INTEGRATED WAREHOUSE AND PRODUCTION SYSTEM - SYSTEM DESIGN AND IMPLEMENTATION

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CERTIFICATE

It is to certify that the work contained* in the thesis entitled " INTEGRATED WAREHOUSE AND PRODUCTION SYSTEM - SYSTEM DESIGN AND IMPLEMENTATION" by Mr. Rohit Bansal (Roll No. 9311421) has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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* Most of the material in Chapter I and Chapter II in this thesis is common with the material in Chapter I and Chapter II, of thesis entitled "INTEGRATED WAREHOUSE AND PRODUCTION SYSTEM - STOCK ASSIGNMENT AND ORDER PICKUP", also submitted for M.Tech degree by Mr. Karunesh Agarwal, Roll No. 9311409.

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ABSTRACT

In this dissertation, an attempt has been made to develop a warehouse planning system to solve the practical problems of Stock Assignment and Order Pickup in a warehouse, optimally and efficiently. Different cases of above two problems have been considered in the system, on the basis of some factors such as number of items to be stored, number of bins of an item to be stored, choice of equipment and mode of retrieval. The cases dealt with, vary from the very simple one, i.e. to store one bin of an item without any choice of equipment to that of the most general case, i.e. to store more than one bin of different items when the best equipment has to be selected and the equipment can handle more than one bin at a time.

Some heuristics have been used to process a request, submitted to the system, in view of the availability of resources in the warehouse at the time of submission. In other words, system operates in a time domain, keeping track of warehouse status at every point in time. The request is processed by the system according to the parameters which are set by the user to simulate actual warehouse environment.

The developed system generates various type of reports to facilitate smooth flow of information to management for decision making purposes. Apart from these reports, the system provides information about performance parameters of some of the warehouse resources. These parameters are helpful in designing a new warehouse and in evaluating the performance of an existing warehouse. The reports and the performance parameters can be used in conjunction to find out the reasons of bottlenecks, if any, in the operation of an existing warehouse.

CONTENTS

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CHAPTER I

INTRODUCTION

1.1 Introduction

The work in this dissertation is motivated by the warehouse problem of a major automobile company. The company has recently established a new plant and the facilities are under construction. In this company, vehicles are assembled on a assembly line, which runs continuously. Frame(chassis) of the vehicle is mounted on the first station of the assembly line and it leaves the system with the vehicle ready for despatch, from the last station. Parts and subassemblies are stored in five different types of bins in central warehouse, which is at a distance from the assembly line.

Reddy J.M.[39] worked on optimizing the number of fork lift trucks and trolleys to be used for transferring parts from the central warehouse to the assembly stations for the assembly purpose. Agarwal K.[1] has extended Reddy's work and considered a different module of the overall problem of warehousing, in which storage and retrieval costs, incurred while storing and retrieving various items inside the central warehouse, are to be minimized. In this dissertation, an on-line information system has been developed to facilitate efficient and fast operation of the warehouse.

At the arrival of a storage menu (list of the items), it is to be decided where to store the items and which equipments should be used for the same. Similarly, for the retrieval menu, it is to be decided which locations are to be accessed to retrieve the bins and which equipments to use. Therefore, to make the processing of the requests fast and efficient, an on-line information system is needed which can help warehouse manager in deciding an optimal policy for storage and retrieval of items in the warehouse. The basic objective in deciding on an optimal policy, typically, is to minimize the overall cost incurred in storing and retrieving the items in the warehouse. The system should also be capable of monitoring the performance of various resources

of the warehouse, so that necessary changes can be made in storage and retrieval policies to meet the changing requirements of the organization.

1.2 Warehousing

In the past few years, the field of warehousing has begun to receive attention that it deserves. However, the warehouse manager has been repeatedly asked to increase customer service and productivity, to reduce inventories, to handle large number of stock keeping units and to improve space utilization in the warehouse.

The functions performed by the warehouse are:

- Receiving the goods from the stores.
- Storing the goods until they are required
- Picking the goods when they are required.
- Shipping the goods to the appropriate user.

Warehouse planning is not simply pouring a concrete slab, installing some racks, and tilting up some walls; nor it is a static one time activity. The changing dynamic environment in which warehouses are planned, quickly renders existing plans obsolete. Therefore we need an on-line dynamic system in which warehouse planning is a continuous activity and the existing plans are constantly being scrutinized and molded to meet anticipated requirements. A successful warehouse maximizes the effective use of the limited warehouse resources while satisfying customer requirements.

The following objectives must be met for a warehouse to be successful:

- Maximize the effective use of space
- Maximize the effective use of equipment
- Maximize the effective use of labor
- Maximize the accessibility of all items
- Maximize protection of all items.

In warehousing a distinction is made between a finished goods warehouse and a raw materials storeroom. The only true distinction between the two are the sources from which the goods are received and the user to which the goods are shipped. A raw

materials storeroom receives goods form the outside source, stores the goods, picks the goods, and ships the goods to an inside user. A finished goods warehouse receives the goods from an inside source, stores the goods, picks the goods, and ships the goods to an outside user. Similarly, an in-process inventory warehouse receives goods from an inside source, stores the goods, picks the goods, and ships the goods to an inside user. Our problem is mainly concerned with the raw materials storeroom and in-process inventory warehouse.

Warehousing for the purpose of commercial gains is at least as old as recorded history. In early writing, man was described as having stored excess food and kept animals for emergency surplus. As civilization developed, local warehouses were introduced. When major trade points were introduced during middle ages, warehousing was established to store the shipped items. All the developments stressed more upon the warehouse location and connection with the external sources and demand points. But as warehousing systems advanced from local warehouses during the middle ages to multi-million dollar facilities, more attention was being paid towards what is going inside the warehouse.

Computer directed warehousing systems using stacker cranes and palletized loads have revolutionized the design and capacity of high volume, large capacity storage facilities. Now more attention is being paid towards saving labor costs, high floor space utilization, improved material flow, improved inventory control, and a lower incidence of misplacement or theft. Maximized benefits of such a system are dependent upon the optimal design of the system, that is, operating cost of warehouse(storage and retrieval costs and time). [Tompkins J. and Smith J.D.[35]].

1.3 Literature Review (review of previous work)

There have been quite a number of studies on various aspects of automated warehousing systems. Four various classes of this literature are given below.

1.3.1 Optimal storage assignment problem

There are very few research papers in the assignment science or operations research literature dealing with the optimal storage assignment in the warehouse. A very limited number of books, articles, and pamphlets dealing with the subject are available in a generally non technical manner.

The location of stocking a warehouse so as to minimize the cost of assembling or handling orders is an important problem in industrial logistics (Neal 1962,1967)[25]. The objective is generally to minimize the man hours required to pick the orders and transport them to the shipping area. The optimal arrangement of stock will depend upon the order picking method, turnover rates, product space requirements, and the demand relationship among the products.

Wilson (1977)[36], discussed some results for a simple out and back picking method. The cube-per-order index (COI) criterion for assigning inventory items to locations within the warehouse was proposed by Heskett[14]. The COI for an item is simply the quotient of the space which must be allowed for the item and the order frequency for the item. Recently, Kallina [20], showed that the COI rule produces an optimal solution to one linear programming formulation of the stock location based on some assumptions.

One of the outstanding series of works is that of Housman, Schwarz and Graves, 1976, [13]. They compared the operating performance of the three storage assignment rules: random assignment, full turnover based assignment and class based turnover assignment. They studied the effect of various storage and retrieval policies on crane travel time per storage and retrieval. They concluded that significant reductions in crane travel time (and distance) are obtainable from turnover based rules.

In the extension to this paper (1977)[12], they included interleaving, i.e. the sequencing of storage and retrieval requests. The paper compares the operating performance of several storage assignment / interleaving policies. It is shown that significant reduction in crane travel time and distance are obtainable in some real world situations via the proposed storage assignment / interleaving policies.

In another paper(1978)[33], using a computer simulation, the scheduling policies, reported in the pervious papers for deterministic environment, have been examined in a stochastic environment and the results are extended to the conditions of imperfect information.

Rosenblatt M.J. and Roll Y. (1984)[32], developed a search procedure for finding a global optimal solution for a specific formulation of the warehouse design problem. In this formulation they considered three types of costs : cost associated with the initial investment, a storage cost and costs associated with the storage policy. They tested several policies ranging from completely random storage to completely grouped storage on a simulated model of a warehouse. They showed that, in certain situations, considerable administrative and other advantages can be realized by group storage with only slight increase in the required warehouse spaces. The proposed procedure enables one to obtain parameters for the design of warehouses so that storage needs are met in an optimal way cost wise. Physical characteristics as well as storage policies are combined to give the best performance.

Linn and Wysk (1984)[22], compared the effects of several control policies regarding stacker movement, sequencing rules, and storage location assignment on the simulated model of an automated storage / retrieval (AS/RS) system. After an extensive number of simulation runs and testing various settings for each of the policies, they came up with several guidelines regarding each class of control policies.

Jay M. Jarvis and Edward D. McDowell (1991)[19] provided a basis for locating product in an order picking warehouse such that order picking time will be minimized. They showed that if the aisles are not symmetrically located about the dock, then simply assigning the most frequently picked items to the nearest aisles will not necessarily minimize the average travel distance. A heuristic based on these conditions was then developed.

Moon-Kyu Lee(1992)[23] dealt with a man-on-board automated storage / retrieval system (AS/RS) where each customer order consists of a number of different items and is picked one at a time. For the system the problem examined was to allocate

storage allocation dedicatedly to the items so that total travel time required to pick all the given orders per period is minimized. He developed a heuristic based on the group technology concept considering both order structure and frequency. Through the heuristic, items with close relationships (identified from the order structure) are compelled to be stored closely in the storage rack.

An outstanding work has been done by Agarwal K.(1995) [1] in which he has taken the problem of correlated assignment of different items in the warehouse. In his work, he has discussed different possible cases of the storage problem for items which are required together from the warehouse. Most of these cases turned out to be either NP hard or NP complete and therefore different heuristics have been suggested to solve different problems.

1.3.2 **Optimal order picking problem**

The order picking problem is the complementary of the above problem where orders are received and the optimal sequence for picking these orders is to be found. Phillips(1977) [28] used the network concept as a basic analytical technique solving order picking problems. In his technique, he considered the nodes of network as locations of items while the distance between two locations is presented as an arc value. Chisman (1977) [6] proposed several methods for picking orders. Orders are divided into three groups: batch carrier, line batch and order picking batch. In carrier batch, geographic similarity of the orders is the main criterion for assigning the orders to such a group. A line-batch group includes all the items which are placed on one shipping line prior to loading on a truck, while the order-picking-batch includes all the items placed on one pallet as a bin-picker passes through the warehouse. Chisman(1977) [6] suggested two methods for bin picking : SN-picking (Stock Number picking) and BL-picking (Bill-of-loading picking). He stated that the choice between SN-picking and BL-picking is a matter of whether one wants to or finds it cheaper to sort out BL's at the bins or in the shipping line. The solution to this problem

was obtained by using a cluster traveling salesman algorithm developed by Chisman (1975) [5].

Elsayed E. A. (1981) [7], presented four heuristic algorithms for handling orders in automatic warehousing systems. The algorithms select the orders that will be handled in one tour in order to minimize the total distance traveled by the S/R machine within the warehouse system. Computer programs are developed for the four algorithms and the optimal tours are found by using the traveling salesman algorithms. Optimal or near optimal solutions are found for the handling problem. The conclusion reached was that optimum policy is problem dependent. Thus, he suggested, for a given problem it is better to evaluate all the policies and pick the one that provides the best results.

Elsayed E. A. and Stern R. G. (1983) [8], presented some new algorithms for processing a set of orders in automated warehousing systems. The proposed algorithms will process the orders by grouping the orders according to some criteria developed by the authors. They proposed four *seed selection* criteria, three *order congruency* criteria and two *order addition* criteria. Thus, they suggested 4*3*2 = 24 possible algorithms for the order picking problem. The traveling salesman algorithm is then utilized to determine the optimal distance traveled within the warehouse for every group of orders. Comparisons of the performance of the proposed algorithms are also presented. The proposed algorithms proved to be data dependent and were sensitive to the capacity of the picking vehicle.

Hwang H, Wonjang B. and Moon Kyu Lee (1988) [18], presented heuristic algorithms for batching a set of orders such that the total distance traveled by the order picking machine is minimized. These algorithms were based on the cluster analysis and their efficiency and validity were illustrated through computer simulation. The results obtained were found to be better than those from the previous studies.

Goetschalckx M. and Ratliff H. D. (1988) [11], presented a special case in which items have to be retrieved manually from both sides of a wide aisle and deposited on a vehicle which travels on the center line of the aisle. The picker will stop the vehicle, pick and load the cases of items onto the vehicle and then drive to the next stop. They

presented an algorithm to determine the optimal number and location of stops and specify the items to be picked at each stop.

Hwang H. and Moon-Kyu Lee (1988) [17], dealt with order processing problem in a man-on-board automated storage and retrieval (AS/RS) system. They presented new heuristic algorithms based on cluster analysis. The algorithms process the orders by batching them according to the value of similarity coefficient which is defined in terms of attribute vectors. To find the minimum travel time for each batch of orders, the traveling salesman algorithm is employed. The results obtained through computer solutions indicate that some of the developed algorithms performed substantially better than those of the previous studies.

1.3.3 Throughput maximization problem

Azadivar F. (1986) [2], in his paper attempted to determine the maximum number of storage and retrieval requests that can be handled by automated warehousing systems under physical and operational constraints. He formulated the system as a stochastic constrained optimization problem and developed an algorithm for its solution. The constraints involved were limits on the average waiting time for retrieve requests and the maximum queue length for the items waiting to be stored. Due to the stochastic nature of the operation of the system, a simulation model was constructed to evaluate the system for various values of its parameters.

Azadivar F. (1989) [3], presented a method for the optimum allocation of the resources between the Random Access spaces and Rack spaces so that the overall throughput capacity of the warehouse is maximized. He formulated and solved the problem as a stochastic optimization problem.

1.3.4 Warehouse design problem

Hwang H. and Chang S. Ko (1988) [16], suggested a Multi-Aisle S/R machine system (MASS) which can substantially reduce high initial investment cost which is a major reason for the low popularity of AS/RS in manufacturing companies. The objective of

their study was mainly related to the design aspect of MASS. With a travel time model developed they determined the average travel time of the S/R machine. They proposed rack-class-based storage assignment procedure and class selection procedure to find out the minimum number of S/R machines required and to identify the number of aisles each S/R machine serves. The procedure applied to example problems showed that MASS is effective in reducing initial installation cost, provided that the pallet demand is relatively low.

Park Young H. and Dennis B. Webster (1989) [37], developed an optimization procedure to aid a warehouse planner in the design of selected three dimensional, palletized storage systems. All the alternatives were compared in the overall model while simultaneously considering the following factors : control procedures, handling equipment movement in an aisle, storage rules, alternative handling equipment, input and output pattern for product flow, storage rack structure, component costs and the economics of each storage system. The above review reveals that there is an abundance of potential research areas that deserve further study.

1.4 Present Work

In this dissertation, as has been stated, problem of storage assignment for a large automobile plant will be dealt with. Here, an attempt to develop an on-line information system has been made, which can facilitate smooth and efficient functioning of the warehouse. The basic objectives of the information system are as follows :

- to make the handling and execution of storage and retrieval requests fast and efficient.
- to optimize the space requirements of the warehouse.
- to find out the utilization of various resources of the warehouse.
- to provide all the information about the warehouse, instantly.
- to reduce the time taken to procure the material from the warehouse.
- to help the warehouse manager in finding out the possible reasons of bottlenecks, if any, in the operation of the warehouse.

In Chapter II, first the problem environment has been described followed by a discussion on the two main problems of warehouse namely - stock assignment problem and order picking problem. Next, the concept of correlated assignment has been discussed, which, in brief, states that the items, which are frequently needed together, should be located in the warehouse in close vicinity so that they can be easily retrieved together whenever needed. After this, classification of the aforementioned problems has been described along with the factors governing this classification scheme. At the end, underlying assumptions have been stated in order to make the problem environment more clear in which the system has been developed.

Chapter III provides a detail insight to the problem structure as a whole and its solution. Here, different methodologies, which had been adopted in solving different problems of stock assignment in the warehouse, are discussed. Also, several steps, involved in solving a stock assignment problem, are described in this chapter. Some special cases are also discussed along with the way in which they had been handled in the system.

In Chapter IV, a detailed description of the steps involved in the evolution of the information system is given. It describes flow of necessary data in the warehouse and a detail description of the data requirement for the development of the system. It also includes a brief description of the procedures, adopted in the system, for a stock assignment problem. The functionality of the information system, as a whole, has been described here with the help of the flow charts. The different hardware and software requirements of the information system are also mentioned here.

Chapter V, essentially, is a user manual which describes the information system from the user point of view. It includes the description of various menu systems and their functioning and various options available to the user for the processing of a request. It also describes the data requirements, format of the data and the ways to enter necessary data into the system for a smooth and trouble free functioning of the system. Different type of outputs generated by the system and their interpretation is

also discussed in this chapter. It also describes how to install the warehouse information system at the user's side.

In Chapter VI, a critical appraisal of the above mentioned information system is done along with the possible improvements in it. In addition, some possibilities of further expansion of the present system are discussed.

At the end, an Appendix has been provided where several underlying functions, which have been used for computational purposes in developing the system, are discussed to enhance the technical understanding of the system.

CHAPTER II

PROBLEM DESCRIPTION

2.1 Description of the problem

In Section 1.1 the motivation for this work has been described. As stated, the work on this dissertation was motivated by the warehouse planning problem of a major automobile company. The company has recently set up a new plant and different facilities at the plant are under construction.

In this company, vehicles are assembled on assembly line, which runs continuously. Frame (chassis) of the vehicle is mounted on the first station of the assembly line, and it leaves the system with the vehicle ready for despatch, from the last station. Different parts and subassemblies are assembled on the chassis at relevant assembly stations as the conveyer of the assembly line moves. These parts and subassemblies are stored in five types of standard size bins in central warehouse which is at a distance from the assembly line. So these parts are to be transferred to the required assembly stations for the assembly purpose by forklifts and trolley attached trucks. Whenever such a forklift or trolley attached truck comes to central warehouse with an order, it is a retrieval request that is to be processed inside the warehouse. As a forklift truck can carry only one bin at a time, the retrieval request associated with it is of a single bin only. But this is not the case with trolley attached trucks, where the retrieval request is a menu, comprising of several bins of several items to be retrieved. Similarly at the receiving end of the warehouse, whenever the in-process inventory or raw material inventory from an external source comes to the warehouse for storage, it is a storage request to be processed inside the warehouse. The storage request can be a single bin storage request or it may also be in the form of a menu.

It has been observed that there are many items which are usually retrieved together because of the nature of the production of the vehicles. But this relation among different items, used in the production, has not been successfully exploited by the company to facilitate efficient and quick retrieval of the items. Therefore, the company needs an information system which can incorporate this relationship among items and formulate a storage and retrieval policy so that the operation of the warehouse can be made cost effective. Moreover, the system should inform the warehouse manager about the current status of the warehouse so that the manager can handle and execute the requests efficiently and quickly. Also, the system should be capable of indicating the performance of various resources of the warehouse so that the manager can change storage and retrieval policies, as and when necessary to meet the changing requirements of the organization. In essence, this information system should be capable of dealing with the following basic problems of warehousing :

2.1.1 The stock assignment problem

This problem, essentially, is to decide where to store the items in the warehouse so that the retrieval of those items can be done optimally and the storage cost is also minimized. Thus both storage cost and retrieval cost are to be minimized at the time of storage itself. Whenever a storage request comes to the warehouse, the system should optimally locate the items in the locations available for storing those items. Optimality criterion can be the distance traveled while storing the item or it can be minimization of the retrieval distance associated with that particular location. Another case is when retrieval is done in batches where the optimality criterion may be to store the items near to the items with which it is frequently retrieved so as to minimize the tour length of the equipment while retrieving the order. Or the objective may be a combination of both of the above objectives.

Whenever a storage request comes to the warehouse and there are various types of equipment which can handle the request, in addition to decide the locations, where the

items are to be stored, the information system should be capable of selecting the equipments for serving each location which has been chosen for locating the item.

2.1.2 The order picking problem

The order picking problem is the complementary problem of the stock assignment problem discussed above. Whenever a retrieval request comes to the warehouse, the system should decide an optimal sequence for picking the items listed in the request from their respective storage locations. Here also there may be several cases depending upon the type of the request menu. Retrieval request may be of a single bin of an item or it may be a menu comprising of several bins of an item. The objective criterion will be same as that of in the previous case, that is, minimization of the retrieval distance or time.

Again, when many type of equipments are there then it is to be decided that which equipment will retrieve which item from which location. When equipment can handle more than one bin at a time, the locations and items which should be served in a particular tour have to be decided. When more than one retrieval requests are there, then keeping the due date constraints in mind, pick up orders can be formed from actual orders i.e. items from two or more actual orders can be clustered together to form a pick up order to be retrieved in a single tour.

2.2 Salient features of the production system

The company presently, produces four to six models of vehicles, but has plans of producing at least twenty different models in recent years. Each model requires different parts or sub-assemblies, but some parts are common to all the models. Each part may be required at more than one station on the assembly line. Same part, which is required at a particular station for a particular model, may be required at another station for another model. The data of number of each part required per vehicle for each model and at each

station is available. Also, each station has a sufficient capacity to accommodate reasonable amount of inventory of different items needed at that station.

It has been assumed that a vehicle production schedule is available, that is, the data regarding the number of vehicles of each type of model to be produced in each batch, is known in advance. So the number of different parts needed at each station on the assembly line can be worked out.

The retrieval request originates from the work stations. It has been observed that the trend of retrieval requests is almost consistent for a particular model. It means that for a particular model, the items which are retrieved together once, are retrieved together most of the time. So, for a particular model, we can store together the bins of items which are frequently requested together. This concept of storing items, needed together, in close vicinity, so that they can be retrieved together easily, is known as correlated assignment concept, and is described in the next section.

2.3. Concept of Correlated Assignment

The concept of correlated assignment is that the stock keeping units (SKU's), or bins of item, which are frequently requested together (that is, in the same order or in the same time window), should be stored together so that at the time of retrieval they can be retrieved together quickly and optimally..

Note that the correlated assignment applies for strict order picking and batch picking operations. We may quantify the desirability of the two items to be stored together by defining a penalty function, that is dissimilarity cost.

Before discussing, in detail, about the nature of dissimilarity cost and its constituents and the methodology of computing it for different situations, the method for computing the distance between two storage locations in the warehouse is discussed.

2.3.1 Distance Function

The distance between two storage locations in the warehouse is to be computed to find out the time taken by an equipment to reach one location from another. This distance is to be computed with the help of a generalized function specified by the user. Therefore, user can modify the way in which the distance is computed depending upon the exact functioning and patterns of movement of the equipments in the warehouse. For a detailed mathematical explanation of the distance function, reader is referred to Section A.1 in Appendix A.

2.3.2 Scheme for Computing Dissimilarity Cost

The dissimilarity cost computation is based on the simple fact that it represents some form of penalty incurred for storing those items in the near vicinity which are not similar, i.e. which are generally not retrieved together. In other words, it could be stated as the cost incurred when items which are frequently retrieved together in the same order are not stored together.

The dissimilarity cost of an item for a particular location depends upon the following factors :

- The frequency of retrieval of the item to be stored with other items already stored in the warehouse.
- The type of item and the number of bins of this item stored in the warehouse.
- The distance of the location in consideration with other occupied locations.
- If more than one bin is to be stored then the interaction between other items being stored and other locations which are being utilized.

Now the methodology for computing the dissimilarity cost is discussed for the three possible cases.

2.3.2.1 When only single bin of an item is to be stored

In this case, only one bin is to be stored at one location and there are "m" locations available to store it. This case is similar to the case in which single facility is to be located at one location out of some pre-specified number of available locations. Here, the dissimilarity cost for a storage location is the result of possible interaction of the items already stored in the warehouse with the item to be stored. The mathematical description of the cost function is given in Section A.2.1 of Appendix A.

2.3.2.2 When more than one bin of same item are to be stored

In this case, more than one bin of same item are to be stored in the warehouse, so the dissimilarity cost will also include the interaction cost of locating the items at more than one location. This interaction will consist of the interaction discussed in the previous case and an additional term which is due to the fact that when more than one bin of the same item is stored, they will somewhat moderate the combined effect of locating all of them. In other words, the combined penalty cost of locating all the bins of the item, will be lesser than the sum of the penalty costs of locating each bin taken separately. Section A.2.2 can be referred to for more involved mathematical description.

2.3.2.3 When more than one bin of different items are to be stored

Here, in addition to the interaction of the item to be stored with other items already stored in the warehouse, an additional interaction will be present because of the interaction among the items to be stored. Therefore it is similar to the case of multi-facility location, in which new facilities, which are to be located at different places, have interaction among them. So the dissimilarity cost will have one component associated with each location for a particular type of item and another component for interaction between two different type

of items being located at two locations. The necessary description of the mathematics involved in computing the dissimilarity cost is given in Section A.2.3 in Appendix A.

2.4 Problem Classification

The problems of stock assignment and order pick up can be broadly classified in two major categories depending upon the type of transporting equipment - fork lift type (i.e. can handle only one bin) or trolley type (i.e. can handle more than one bin). These two categories can be further subdivided on the basis of whether the bin are stored or retrieved in batches or only a single bin is handled at a time. There can be a further subdivision of the problems on the basis of whether the equipment is preselected by the user, before the execution of request, or the equipment is to be specified by the system itself. Agarwal K. (1995) [1] has given the classification of stock assignment problem in a tabular form in his work. Interested reader may refer it for further details on the nature of these problems. The classification of order pick up problem can be done on the same lines and these classified problems are also dealt with in the same way as of the problems of stock assignment.

2.5 Assumptions

In this section we all the assumptions are listed which have been made while formulating the problems and designing the information system. The assumptions are :

- The warehouse in consideration is a rectangular warehouse with an input dock and several output docks. There are several aisles parallel to each other. The row space is continuous.
- Bin sizes are standardized and are integral multiple of unit size.
- Each bin holds only one type of item at a time.
- Storage and retrieval requests are for the entire contents of the bin.

- Several type of equipments are there, with constraints on the type of bins they can carry and the locations which they can serve.
- Interleaving is ignored. All storage and retrieval functions are initiated with the equipments at the input / output dock.
- In a request all the bins of one type of item are of same size.
- The equipment acceleration and deceleration time is ignored.
- Storage requests are served on first come first serve (FCFS) basis.
- Equipment scheduling is not considered.

CHAPTER III

SOLUTION METHODOLOGY

The main objective of this dissertation is to develop a computerized system for the management of warehouse and integrating it with assembly line and production system. The mathematical structure and the solution methodology for this problem has been discussed by Agarwal K. [1]. In this dissertation, aim is to implement the methodology suggested by him. The approach adopted here, is to identify a common core methodology which will be able to handle most of the different stock assignment problems with an addition of few specific features suited for each of the problem. In this chapter, main steps for this core methodology will be identified along with the variations which are needed for each of the specific problem. After discussing the methodology to the stock assignment problem, the core steps for order pick up problem, followed by specific variations of this problem will be discussed.

3.1 Distance Computation

Distance between two locations and between input or output docks and a specific location is an important measure as the cost of retrieval and cost of storage is dependent on these measures. Distance function, required to describe these distances will vary from application to application. To provide flexibility, a generic function has been selected which is capable of modeling most of the distance measurements by setting up of parameters. In practice, in warehouses the movements of the equipment will be along an aisle (horizontal movement), across an aisle (horizontal movement) and along the height of racks (vertical movement). However, is some cases it is possible to move the

equipment along the shortest path (Euclidean distance) such as across the racks. The generic function, selected for distance computation, provides for

(a) Different weights to be assigned for computation of travel times in the horizontal, vertical and across the aisle movements as the speed of equipment will differ for each of such movement.

(b) Across the aisle movement can, generally, take place, either at the beginning or at the end of the aisle and accordingly, to access a location in another aisle, the equipment has to move either to the beginning or to the end of aisle.

(c) In the case of vertical movement in the same aisle, the movement can be of one of the following type :

- the equipment has to be moved to the ground position and then again to the appropriate height after the required horizontal movement.
- the equipment can be moved horizontally without changing the vertical position and hence vertical distance moved will be the difference of the vertical location of the two points.
- in some cases, the pick up arm can be moved across the rack along the shortest path.

The generic function which is selected for computations purpose is described in detail in Section A.1 and is given in mathematical form in Equation A.1 there, which is described here for a quick reference.

$$\begin{aligned} d_{ij} = [\,& H\{d|X_i - X_j|^\wedge a + e * \min[(X_i + X_j), (2 * L - X_i - X_j)]\} \\ & + A|Y_i - Y_j|^\wedge b + V\{(f(Z_i + Z_j) + g|Z_i - Z_j|)^\wedge c\}\,]^\wedge d \quad \ldots\ldots\ldots\ldots \; 3.1 \end{aligned}$$

Where

H is the weight for horizontal distance .

V is the weight for vertical distance.

A is the weight for across the aisle distance.

L is the length of the rack along the aisle

Xi, Xj are the x-coordinates of locations i and j, along the aisle.

Yi, Yj are the y-coordinates of locations i and j, across the aisle.

Zi, Zj are the z-coordinates of locations i and j (vertical movement).

a, b, c, d are the constants to determine the type of distance function, that is, rectilinear, Euclidean or squared Euclidean.

e, f and g are the dependent binary variables which take value 0 or 1 to select the appropriate horizontal movement.

In order to minimize the cost of transporting different items from or to the storage locations in the warehouse, distance traveled by an equipment from one location to another is found. Also the distance traveled by the equipment from dock to first location and then the returning distance to dock is also calculated. These distances are computed using the distance function discussed above.

3.2 Cost Computation

The total cost incurred in transporting the items in warehouse may be a combination of the following three cost components :

Storage Cost : This is the cost incurred while storing an item or bin in the warehouse to a particular location with the help of a specified equipment from a specified input dock. It includes the transportation cost and the labor cost, incurred by the equipment while transporting the item from the dock to a location inside the warehouse where the item is to be stored. It is a function of location to be accessed, the dock at which item is to be received, equipment to be used for transportation and the type of bin stored at the storage location and the item to be stored.

Retrieval Cost : This is the cost incurred while retrieving an item or bin from a particular storage location in the warehouse to a specified output dock. It includes the transportation cost and the labor cost incurred by the equipment while transporting the item from a storage location inside the warehouse to the output dock from where the item is to be shipped. It is a function of location from which the item is to be picked, equipment used for transportation and the output dock at which item is to be shipped.

Dissimilarity Cost : This cost is a form of penalty cost as is described in Section 2.3.2 of Chapter II. It is incurred when two items which are, generally, retrieved together are not stored in near vicinity in the warehouse. As is described in Section 2.3.2, it takes different values depending upon the storage pattern, retrieval pattern and the number of type of items listed in a request. As is described in this section, if the retrieval pattern is single bin there will not be any interaction among the bins and hence, no dissimilarity cost. If the retrieval pattern is multiple bin at a time then the interaction among same item as well as different items will also come into picture. When only one type of item is to be stored then there will not be any interaction among the items but there will be interaction among different locations in which same item is stored. Whereas, when different items are to be stored there will be an additional interaction term which will take care of the interaction among different item types.

The cost incurred in storage / retrieval of items in / from the warehouse depends upon the distance traveled by the equipment used. Equipment velocity, in horizontal and vertical direction, its loading and unloading time, is used to compute the time taken by the equipment in traveling from one location to another. This time is multiplied by the operating cost of that particular equipment to find out the cost incurred by the equipment in traveling. Here it should be noted that the transportation cost is a function of the equipment used, as different equipments have different velocities and different operating

cost. Apart from this cost; some personnel cost is also involved, which is computed using the manpower requirements for the equipment and the labor cost prevailing in the industry. These two cost components are referred to either as storage cost or retrieval cost depending upon whether the request is of storage type or retrieval type. In addition to the cost incurred in transporting the items inside the warehouse, dissimilarity cost in one form or another is also to be taken into account while storing the items in the warehouse. Therefore, total cost includes following two major components :

- cost incurred in transportation of the item from dock to the location. It is either storage cost or retrieval cost or a combination of both depending upon the case.
- dissimilarity cost which is incurred because of locating the item at that location and is a function of the item to be stored, location at which item is to be stored and the way in which other items are stored in the warehouse.

Here, it should be made clear that when the items are to be retrieved from the warehouse, only transportation cost is considered.

3.3 Solution methodology for stock assignment problem

Though, the specific steps involved in solving a particular stock assignment problem, depend upon the problem environment, there are some general steps which are common to all the different cases of this problem. These steps are described here and the steps which are specific to a case are given under the description of that particular case itself.

Step 1 : System Initialization

User is required to specify different inputs regarding the warehouse structure (location numbers, aisles etc.), the distance function, the cost function, the list of available equipments with their characteristics. This step initializes the warehouse environment according to the needs of the user.

Step 2 : Stock Assignment Input

Request is taken from the user with all the necessary details like list of the items which are to be stored in the warehouse, their quantities along with the bins in which the listed items are stored. If equipment is to be selected by the user, then the list of equipments to be used for different items is also taken, from the user. Here, while taking the equipment list, a check is made whether the equipment specified by the user can serve the specified bin (storage request) or not. This check is performed with the help of constraints imposed on bin - equipment interaction.

Step 3 : Location Availability Check

A check is made to find whether there is any free storage location available in the warehouse to store the items listed in the request. If there is no space available in the warehouse, the request is not executed and appended to the wait queue to be executed later.

Step 4 : Bin Location Availability Check

For each bin, to be stored, the set of available location is identified amongst those locations which are available for storage. Each available location is checked for its suitability to size and the item to be stored. It there is no storage location available in the warehouse then that bin will be discarded from the request and is appended to the wait queue.

Step 5 : Equipment Availability List

For each bin and for each location in the available locations list, an equipment selection list is prepared in order of the storage cost for that item - bin combination from among the available equipments for that item - bin combination.

Step 6 : Location Assignment

This step will assign a location to a bin amongst the list of available locations. This step will differ from solution to solution. Depending upon the case, least cost location assignment, maximum clique problem, generalized assignment heuristic or quadratic assignment problem is to be solved.

Step 7 : Equipment Assignment

For the selected bin - item - location, the available equipment is selected from the equipment availability list.

It may be noted that Step 6 and Step 7 may have to be done jointly when there are limited number of equipments available.

Step 8 : Equipment Tour

After selecting the locations at which items are to be stored and deciding on the equipments to be used for the purpose, the sequence of the storage operation is decided. This sequence is decided for each equipment selected for storing the items. The objective of deciding the sequence of operation is not only to minimize the equipment movement and thus to minimize the operating cost of equipment but also to minimize the number of equipments needed for storage purpose.

If an equipment is able to handle more than one bin at a time, then determining the sequence of execution of a request is a typical k-Traveling Salesman Problem (TSP). A simple but appealing heuristic to solve this problem is nearest neighbor algorithm. The steps involved in this algorithm are as follows :

Step a : Start with any arbitrary location to form a partial tour.

Step b : Among the locations not included in the tour select the location which is nearest to the location currently at the tail of the tour and add it to the tail of the tour.

Step c : Stop if all the locations are included in the tour else go to step b.

The above steps will generate a full tour which comprises of all the locations which are to be accessed. Now, this tour is further divided into partial tours depending upon the capacity of the equipments.

Step 9 : Equipment Schedule

After determining the sequence of operation for every tour of each equipment selected, time taken by the equipment for each tour is computed. This time, is the time taken by the equipment in traveling to all the storage locations in a particular tour plus the loading time at the receiving dock and the unloading time of bins at the selected locations. The unloading and loading times are function of the type of equipment and the type of bin handled by that equipment.

Step 10 : Output Generation

This step summarizes the whole operation which is carried out in the form of above nine steps. Here an output is delivered to the user which contains the information regarding locations where the bins are to be stored, which equipments are to be used for storing the bins, schedule of sequence in which the bins are to be carried to their respective locations and the schedule of the equipments.

Next, some specific cases will be discussed. In all these cases, all the above steps are same except Step 6 and Step 7 which differ from case to case. Essentially, in all the following cases, these two steps are explained in detail according to the problem

3.3.1 Single item type is to be stored

This is the case when only one type of item is to be stored in the warehouse. Therefore, the dissimilarity cost will not include the term resulting from the interaction of different item types. This case can be further sub-divided into two categories depending upon the equipment selection mode.

3.3.1.1 Equipment preselected by the user

Here the equipment for each bin is already selected by the user at the time of submitting the request to the system. Therefore, system need not to select the equipment for the selected locations. In this case, Step 6 and Step 7, mentioned above will be executed as follows :

- A list of available storage locations is generated for each bin - equipment combination specified in the request. While selecting the available locations for each combination, following two constraints are to be satisfied :

  Constraint 1 : storage location should be accessible by the specified equipment i.e. the height of the location should be less than or equal to the maximum accessible height of the equipment.

  Constraint 2 : the location should be able to accommodate that bin type i.e. number of free spaces available at the location should be greater than of equal to the space required by that bin.

- Cost for each storage location appearing in the generated list is computed as discussed in Section 3.2 above. This cost will include storage as well as retrieval cost and dissimilarity cost also. If the retrieval pattern is more than one bin at a time, then the interaction term resulting because of the interaction among the same item type stored at different locations in the warehouse will be included. But if retrieval pattern is single bin at a time then this interaction term will be absent.
- All the available and feasible locations are sorted in ascending order of the cost, associated with each of them. Locations are selected from the top of this list so as to

fulfill the objective of minimizing the total cost. The number of locations selected depend upon the number of bins to be stored.

When the retrieval pattern is multiple bin at a time and the number of bins, which are to be stored in the warehouse, is greater than one, then the cost of each location is to be recomputed each time a selection is made. The reason is that when one bin is stored in the warehouse at the selected location, total number of bins of that item type in the warehouse changes and it affects the dissimilarity cost. This effect is taken into account by recomputing the cost every time a selection of location is made. This problem is solved as a sequence of Maximum Weight Clique Problem and the heuristic used for its solution is again a sequential greedy search heuristic which finds out the node having minimum weight at its vertex among the unselected nodes so far.

- This procedure is repeated for each bin - equipment combination but after updating the total number of bins stored in the warehouse taking into account the previous assignment of bins to locations.

3.3.1.2 Equipment is to be selected by the system

In this sub division, the case is considered when equipment is also to be selected by the system along with the locations. Here, Step 6 and Step 7 will be executed as follows :

- The cost for each storage location appearing in the list is computed as discussed in Section 3.2 on the basis of available equipment in the available equipment list for that location, as prepared in Step 5. This cost will include storage as well as retrieval cost and dissimilarity cost also. If the retrieval pattern is more than one bin at a time, then the interaction term resulting because of the interaction among the same item type stored at different locations in the warehouse will be included. But if retrieval pattern is single bin at a time then this interaction term will be absent.

- All the available locations are sorted in ascending order of the cost associated with each of them. Locations are selected from the top of this list so as to fulfill the objective of minimizing the total cost.
- After selecting a location from the top of this list, Step 7 i.e. Equipment Assignment, is executed and then Step 5 is re - executed for each of the remaining locations taking into consideration this assignment and Step 6 to 7 are repeated. In multi bin storage case, selection of equipment is done in a different way. Following are the steps involved in the selection of equipment for selected locations :

Step a : select the desired number of locations from the list of storage locations corresponding to the minimal cost associated with each location.

Step b : for each selected location make a set of type of equipments which can serve that location. Arrange the list of selected locations in the ascending order of the cardinality of this set.

Step c : select the minimum cost available equipment for the location on the top of the list and delete this location from the list.

Step d : for the current location on the top of the list check whether it has some equipment in common with the equipment already selected for previous locations. If there are any, assign this location to that equipment, if the equipment has required space. Otherwise assign minimum cost available equipment to the location under consideration.

Step e : delete the assigned location in step d from the list and then go to step d if the list is not null.

3.3.2 Multiple item types are to be stored

This is the case when the number of items to be stored is more than one. However, bins may be stored one at a time or multiple bins at a time. Bin sizes may be same or different

depending upon the situation. Here, dissimilarity cost will include the component resulting from the interaction among various item types. In this case, an added dimension of the problem is that for every available storage location there may be a set of bin types which can be stored at that location. Therefore, for every location, cost is to be computed for all combinations of bin type and storage location and an assignment of a bin type to a location is to made. Therefore, the basic nature of the problem here is of transportation (generalized assignment) type where each bin type is to be located in some location depending upon the available free space at that location and the size of bin. In all these problems, cost of the unallocated bin location combination is dependent on the already assigned bin - locations. Hence only a sequential type of heuristic, where at each step one assignment is made will be considered. Therefore, heuristic used here is Russell's heuristic, which works on the concept of minimum cost criterion. Depending upon the equipment selection mode, this case also can be divided into two cases :

3.3.2.1 Equipment preselected by the user

Here, the equipment for each bin is already specified by the user at the time of submitting the request to warehouse. Therefore no equipment selection is needed by the system. In this case Step 6 and Step 7 mentioned in Section 3.3 will be executed as given below :

- for each available location, found in Step 4 of Section 3.3, cost associated with it is computed for each bin type - equipment combination. This cost will include storage cost, retrieval cost and the dissimilarity cost, components of which are decided by the retrieval pattern. Here, one point is to be noted that in case of equipment being able to handle multiple bins, only average storage cost is considered in cost computation as exact cost will depend on the tour of the equipment. If the specified bin can not be stored at that location, because of not being able to satisfy any of the two constraints mentioned below, then a very high cost is assigned to that location for that particular bin - equipment combination :

Constraint 1 : storage location should be accessible by the specified equipment i.e. the height of the location should be less than or equal to the maximum accessible height of the equipment.

Constraint 2 : the location should be able to accommodate that bin type i.e. number of free spaces available at the location should be greater than of equal to the space required by that bin.

- the storage locations with minimum cost is selected.
- locations are selected from the top of the list so as to minimize the total cost incurred in the operation. The cost is recomputed after taking this assignment into account and steps are repeated for the remaining locations.

3.3.2.2 Equipment is to be selected by the system

In case equipment is able to handle only one bin at a time, the steps are similar to those described in Section 3.3.2.1, except that, for each bin - location combination, a list of available equipments will be prepared and equipment is selected from this list. However, in case the equipment can handle more than one bin, the procedure will be different. Here the main emphasis is to minimize the number of equipment trips needed to process the request. Therefore, this case is handled in a somewhat different way as compared to previous cases. Here, Step 6 and Step 7 will be executed as follows :

- first bins, which are to be stored, are assigned to available equipments. This assignment problem is a well known Bin Packing problem. The heuristic used for its solution is First Fit Decrease (FFD) given by Kraus et al. [21]. Following are the steps involved in this heuristic, which is customized to the chosen problem :

  Step a : arrange the bins in descending order of bin sizes.

  Step b : arrange the equipments in ascending order of their capacity.

  Step c : equipment on the top of list is taken and it is assigned as many number of bins, from the top of bin list, as it can accommodate, according to its capacity.

Step d : assigned bins and equipment are removed from their respective lists.

Step e : Step c and d are repeated for the remaining bins.

- Now, this problem is similar to the case when equipment is preselected by the user. The only difference is that here equipments are assigned by the system but after assignment the problem is similar to that case. Therefore, now it can be solved by the method described above in Section 3.3.2.1.

3.4 Solution methodology for order pick up problem

In order pick up problem, the request is of retrieval type in which there is a list of items which are to be picked from the warehouse. Here, the only cost involved is retrieval cost which is incurred because of equipment movement. Therefore the objective here is to minimize the distance traveled and also to minimize the number of equipments needed to execute a request. In the following text, a general method is described to solve the order picking problem. But the exact method to solve a given problem depends upon the problem environment. Therefore, after describing the general steps for solving the problem, exact methods are presented for some specific cases.

Step 1 : System Initialization

User is required to specify different inputs regarding the warehouse structure (location numbers, aisles etc.), the distance function, the cost function, the list of available equipments with their characteristics. Here it is to be noted that this step is not performed every time a request is submitted to the system. It may be executed in part, either in the form of specifying a different cost function or a different distance function.

Step 2 : Order Pickup Input

The request is taken from the user with all necessary details like list of the items which are to be retrieved from the warehouse and their quantities. If equipment is to be selected by

the user, then the list of equipments to be used for different items is also taken from the user. If their is any time constraint for execution of the request, then that is also taken from the user in the form of due date.

Step 3 : Item Availability Check

A check is performed whether the specified items are available in desired quantity or not. It is done with the help of quantity ordered for the item and the stock level of item in the warehouse. If any item is not available in the warehouse in desired quantity then that item is discarded from the request and appended in the wait queue.

Step 4 : Location Availability List

For each item, listed in the request, a list of those storage locations is found where the item is stored in the warehouse.

Step 5 : Equipment Availability List

For each available location and each bin in the available locations list, an equipment assignment list is prepared in order of the storage cost for that item - bin combination.

Step 6 : Location Assignment

From the location availability list and equipment availability list, locations from where the order has to be picked up, are selected. This step may be executed differently for different problems.

Step 7 : Equipment Assignment

For the selected bin - item - location, the available equipment is selected from the equipment availability list.

It may be noted that Step 6 and Step 7 may have to be done jointly when limited number of equipments are available as the problem is equivalent to three dimensional transportation problem. A simple heuristic to solve this problem will be to select sequentially the least cost location - equipment combination.

Step 8 : Equipment Tour

The sequence of retrieving the items from the warehouse is found. In determining the sequence of retrieval, the objective is not only to minimize the cost of retrieval but also to minimize the number of equipment trips needed for retrieval.

Step 9 : Equipment Schedule

After determining the sequence of operation for every tour of each equipment selected, time taken by the equipment in each tour is computed. This is the time taken by the equipment in traveling to all the storage locations in a particular tour plus the unloading time of bins at the selected locations and the loading time at the receiving dock. The unloading and loading times are function of the type of equipment and the type of bin handled by that equipment.

Step 10 : Output Generation

In this step, all the results, which are arrived at in the above nine steps, are summarized and delivered to the user. In includes which item is to be picked from which locations, which are the bins to be moved and which equipments are to be used for retrieval purpose. It also provides the sequencing of retrieval operation for each equipment in each tour.

Now some specific cases will be discussed in the text to follow. In all these cases, all the above steps are same except Step 6 and Step 7, which differ from case to case. Essentially,

in all the following cases, these two steps are explained in detail according to the problem environment :

3.4.1 Equipment preselected by the user

In this case, equipment is specified by the user before submitting the request to warehouse. Therefore, system need not to select the equipment for any item listed in the request. Here, Step 6 and Step 7 will be executed as follows :

- the list of locations, generated in Step 4 mentioned above, is pruned further because of the following two constraints which should satisfy for the feasibility of the selection of the locations.

  Constraint 1 : the specified equipment for the item should be able to access the location i.e. height of the location should be less than or equal to the accessible height of the equipment.

  Constraint 2 : the specified equipment should be able to handle the type of bin which is stored at that location.
- cost is computed for each location, appearing in the pruned list, as discussed in Section 3.2. Here only retrieval cost will be associated with the location which is due to the equipment movement.
- locations are arranged in the ascending order of the cost associated with them.
- locations are selected from the top of list for the specified item. The number of locations selected from the list depends upon the quantity ordered for the item.
- above methodology is repeated for each type of item listed in the request.

3.4.2 Equipment is to be selected by the system

Here the system has to select the locations for retrieval as well as the equipments to be used for retrieving the items listed in the request. In case where the equipment can handle more than one bin at a time, Step 6 and Step 7 will be executed as follows :

- for each location, appearing in the list of possible locations, a list of equipments, which can serve that particular location, is generated. It is done keeping in view the two constraints which are given below :

  Constraint 1 : the equipments in the list should be able to handle the bin stored at that particular location.

  Constraint 2 : each equipment in the list should be able to access the location i.e. height of the location should be less than or equal to the accessible height of the equipment.

- that equipment is selected which is common to maximum number of equipment lists to the available locations. After this, the least cost location, with respect to this equipment is selected. The location, nearest to so far selected locations, is selected till the equipment is fully utilized. Then the nearest neighbor tour for these locations is constructed.
- the above step is repeated for remaining locations.

CHAPTER IV

SYSTEM SPECIFICATION AND DESIGN

This chapter covers the systematic way in which the Integrated Warehouse Planning System has evolved out of the problem discussed in Chapter II. It covers the entire development phase of the system, right from conceptual design up to the actual design. The chapter is broadly divided into two parts. First part is system specification, in which the system is described conceptually with the help of data flow diagrams, structured specification of the processes involved and data required for the system. In system design part, actual design of the system is described which consists of the design of the underlying database, program flow charts and input & output design of the system.

4.1 System Specifications

4.1.1 Data Flow Diagram

The brief data flow diagram, along with the description of the processes involved, for the Warehouse Information System is shown in Fig 4.1.

The requests are sent to the warehouse either by assembly line (termed as retrieval requests) for the delivery of items or by the purchase department (termed as storage requests) for storing the items in the warehouse. In both the cases, request is processed by the system and processing instruction is given to the warehouse personnel to execute the request physically. The processing instructions include the necessary equipment(s) to be used, the warehouse locations which are to be accessed, the sequence in which these locations are to be accessed etc.

A detailed data flow diagram of the information system is shown in Fig 4.2. It illustrates the step by step procedure of executing a request sent to the warehouse. The brief description of all the processes involved in the procedure is given below :

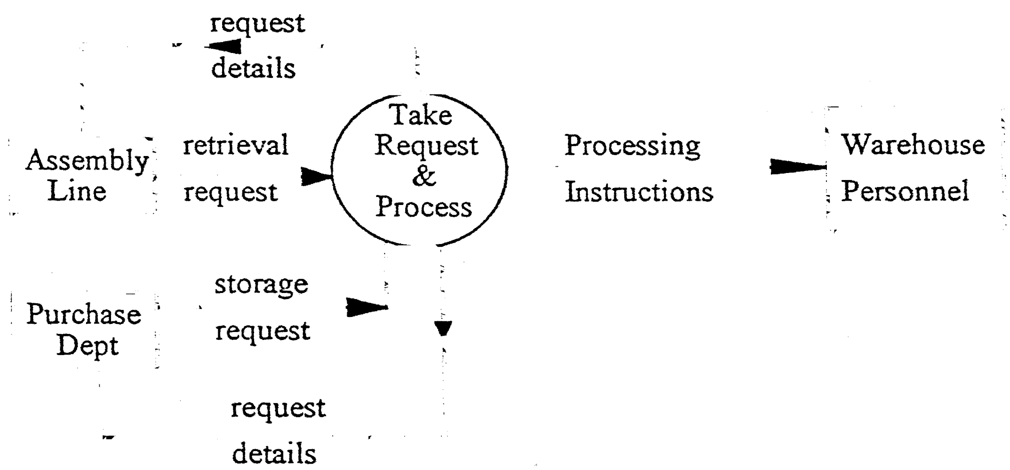


Fig 4.1 Data Flow Diagram

Process 1 : The various functions of Process 1 are

- to take a request and all its details e.g. request number, type of request (storage/retrieval), items, quantity of each item, date and time of receiving etc.
- to generate details of the request and to send these details to Process 2.

Process 2 : The functions of Process 2 are

- to check the incoming request with the request master file to ensure that two requests do not have the same request number.
- to ensure that the product codes listed in the request are valid. It is done with the help of the product master file.

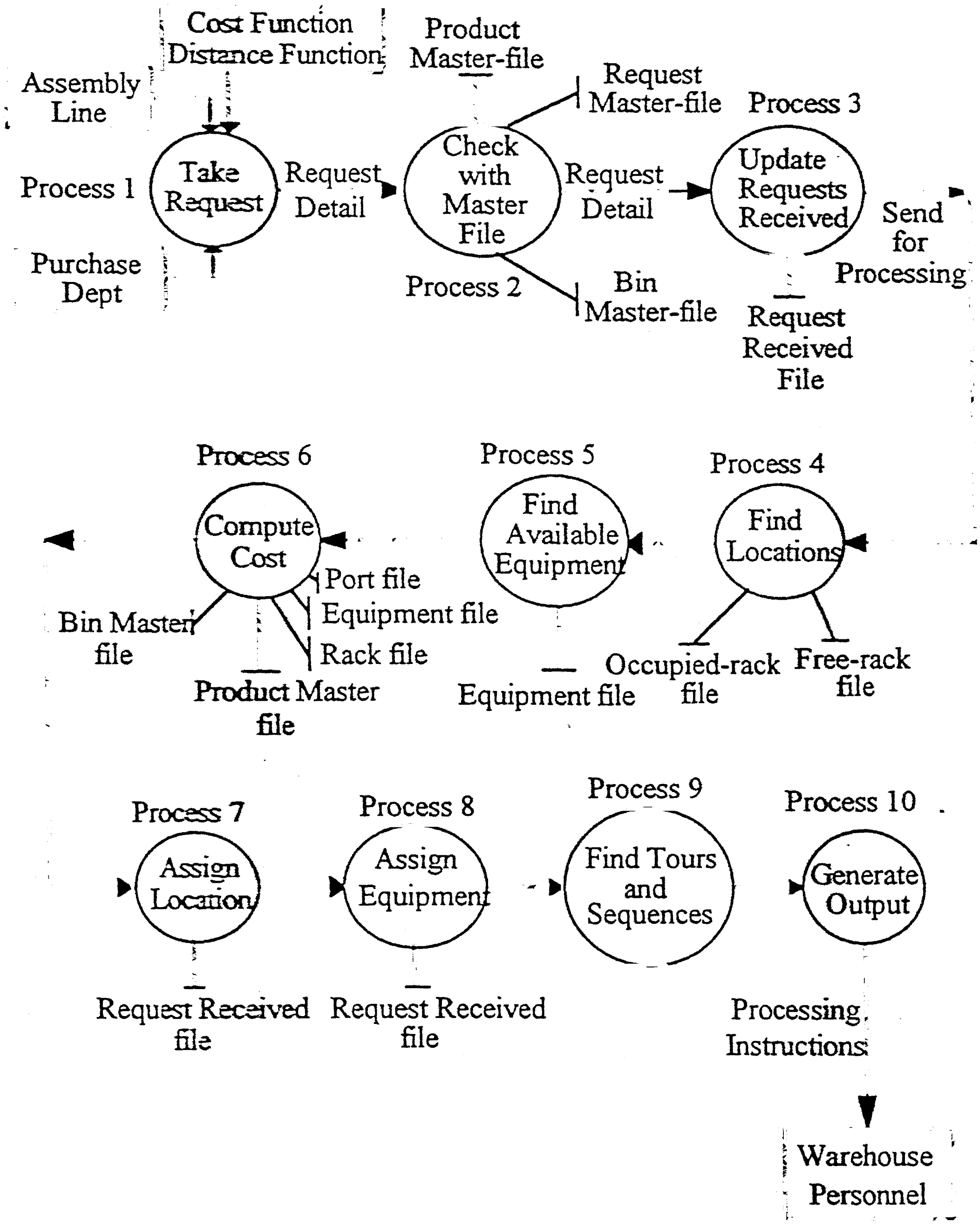


Fig 4.2 Detailed Data Flow Diagram

- to ensure that the bins listed in the storage request are valid. This checking is performed with the help of bin master file.

Process 3 : In this process, the request received file is updated with the details of the current request.

Process 4 : The functions of Process 4 are

- to find out the available locations in the warehouse where items can be stored (storage request) or from where items can be retrieved (retrieval request). It is done with the help of two files - one which has all the free locations and another which has all the occupied locations of the warehouse.
- to send the details of available locations to Process 5.

Process 5 : In this process, following functions are performed

- for each location, found in Process 4 above, a list of available equipments is found. This step is carried out only if the equipment is not specified by the user. Selection of equipment is done with the help of equipment master file.
- this list of equipments is send to Process 6.

Process 6 : The functions of this process are

- to compute the cost incurred either in storing an item to a given location or retrieving an item from that location. This cost is computed for each location and for each equipment in the list of equipments associated with that location.
- this cost is computed according to the setting of various parameters and with the help of equipment characteristic data stored in equipment file, location data stored in rack file, port data stored in port file, bin characteristic data stored in bin master file and product data in product master file.
- to send the cost details to Process 7.

Process 7 : The functions of this process are

- to select the locations for different items, listed in the request, depending upon the cost computed in Process 6.
- to assign the selected locations to the items, listed in the request, and to store this assignment information in request received file
- to send the location assignment scheme to Process 8.

Process 8 : Following functions are performed in this process

- to assign various items, listed in the request, to various equipments either for storage or for retrieval.
- to store this equipment assignment information in request received file and to send this scheme to Process 9.

Process 9 : The functions of Process 9 are

- to find out the tours for each equipment, used in the request, either for storing the items or for retrieving the items.
- to find the order in which the items, in a given tour, are to be stored / picked.
- to calculate the time taken in completing a tour. This is computed for all the tours of each equipment used in the request.

Process 10 : The functions of this process are

- to generate the output of the processing of the request which comprises of the locations and equipments assigned to each product in the request as well as the sequencing of execution of the request. This sequence comprises the order of accessing different locations for each tour of each equipment. The starting time of each tour is also computed. All this processing is accomplished with the help of the request received master file.
- to generate a hard copy of the output, if desired by the user, to facilitate physical execution of the request by the warehouse personnel.

4.1.2 Structured specification of procedures

A brief description of the procedures, involved in different processes, mentioned above, is given below for better understanding of the system. The following description is given in simple English language but in a little bit of structured form so as to facilitate easy conversion to any computer programming language .

4.1.2.1 Procedure for Process 1

```
for each incoming request do
    take request no, type of request (storage / retrieval), date and time of request, items
    listed, their quantity;
    send details of request to process 2;
endfor
```

4.1.2.2 Procedure for Process 2

```
for each request do
    check in the request master file;
    if request is present in the request master file then
        give message that this request is already present;
        discard request;
    else
        send request details to process 3;
    endif
endfor
```

4.1.2.3 Procedure for Process 3

```
for each request do
    enter all the request details in the request received file;
endfor
```

4.1.2.4 Procedure for Process 4

```
for each item in the request do
    check free rack file;
    check occupied rack file;
    if any free location is available then
        find out the list of available locations in the warehouse from free rack file;
    else
        put the item in wait queue;
    endif
    send the list of available locations to process 5;
endfor
```

4.1.2.5 Procedure for Process 5

```
if equipment is to be selected by the system then
    for each location available in warehouse do
        find out the list of equipments available for the location;
        send the list of equipments to process 6;
    endfor
endif
```

4.1.2.6 Procedure for Process 6

```
for each location available in the warehouse do
    for each equipment in the equipment list for the location do
        find out the distance traveled by the equipment to access the location with the help
                    of distance function;
        compute cost incurred in the equipment movement;
        if request is storage type then
                compute dissimilarity cost according to the processing parameters;
        endif
```

```
        calculate total cost as sum of above two costs;
    endfor
endfor
```

4.1.2.7 Procedure for Process 7

```
sort the locations in the ascending order of cost associated with them;
do until all the items are assigned to locations
    assign the location on the top of sorted list to the item;
    store this location assignment in the request received file;
    delete the selected location from the list;
enddo
```

4.1.2.8 Procedure for Process 8

```
if equipment is to be selected by the system then
    for each selected location for the items listed in the request do
        find out the most optimal equipment for the location selected;
        store this equipment assignment in the request received file;
    endfor
endif
```

4.1.2.9 Procedure for Process 9

```
for each equipment selected for the request do
    find out different tours for the equipment depending upon its capacity and number of
        locations assigned to it;
    for each tour of the equipment do
        determine the sequence of accessing the locations in each tour on the basis of
                minimum cost incurred in equipment movement;
        compute the time taken by the equipment in completing the tour;
        store the time taken and sequence of operation for the tour in request received file;
    endfor
```

store the tour information for the equipment in request received file;

endfor

4.1.2.10 Procedure for Process 10

```
for each item in the request do
    list all the locations assigned for the item;
    list all the bins which are to be handled for the item;
    list all the equipments used for transporting the item;
endfor
for each equipment selected to execute the request do
    for each tour of the equipment do
        list the sequence of operation for the tour;
        list the starting time of tour;
    endfor
endfor
if user asks for a print of the output then
    print the output with all the details;
endif
```

4.1.3 Broad specification of data

The processes discussed in the previous section require a large variety of data ranging from products to bins and ports. Every resource of the warehouse needs to be identified clearly and uniquely to avoid any ambiguity. It means all the resources should have a unique identification number attached to them which distinguish them from other members of the same class. Apart from this, products' name, bin types and rack types are required for illustration purposes. Capacity of each bin for every product, capacity of each equipment and capacity of each rack in terms of number of rows and columns are required

to simulate the real system. To create a more realistic system, further constraints in the form of maximum permissible height of storage for bins and maximum accessible height for equipments have to be specified. For static components, like racks and ports, location (x and y coordinates) is required for the computation of time taken to execute the request. Horizontal and vertical velocities of every equipment are also required for the same purpose. Operating cost and man power required for each equipment and loading and unloading time for each bin-equipment combination are to be specified to evaluate the cost incurred in executing a request. A more illustrated form of data specification is given below :

4.1.3.1 Data about product

For unique identification of the products, typically, a code is assigned to each product. Apart from code, name of the product is required for the illustration purposes. To keep track of the stock level, at a given point in time, of the product in the warehouse, total quantity of the product is required.

4.1.3.2 Data about bin

Bins are broadly classified in some types. The warehouse may have several bin of the same type. Each type of bin occupies a definite amount of storage locations and cannot be stored beyond a certain specified height. But to uniquely identify a bin, a unique identification number has been given to each bin. In addition, data for bin - product relationship such as a particular bin type can handle what products and in what quantity is also needed.

4.1.3.3 Data about equipment

A unique identification number, cost of the equipment, capacity of the equipment, manpower required to operate the equipment, operating cost and the horizontal & vertical velocities of the equipment are data-bits which are needed. Data regarding the equipment relationship with bins such as which equipment can handle which bin type and what is the

loading and unloading time for the a particular equipment - bin type combination is also needed.

4.1.3.4 Data about storage location

A unique identification number has been given to each of the rack. Type of the rack, number of rows and columns in a particular rack and its location (x and y coordinates) in the warehouse are the required information.

4.1.3.5 Data about port

A unique identification number, type of the port (whether input or output or both) and its location in the warehouse are needed to identify a given port.

4.1.3.6 Data about request

A unique identification number, type of the request (storage or retrieval), date and time of arrival at warehouse, products which are to be transported, their desired quantity and due date of the request, if any.

4.1.3.7 Data about warehouse environment

It includes the exact specification of distance function to be used for computing the distance to determine the cost incurred in equipment movement. The system should also know the criterion of computing distance from the specified distance function which may be either to consider the items in the same aisle only on in the same row / column only. The dissimilarity cost is dependent on the method used for execution of the request for which the system should be able to know whether the mode of storage is single bin at a time or multiple bin at a time, whether equipment selection is to be done by the system or user will specify the equipments a priori, whether the mode of retrieval is single bin or multiple bin. Apart from this, the system should be told a way of computing the correlation among various products. Different weights assigned to input and output ports, unit length measurement along the racks and in vertical direction and the region for computing the dissimilarity cost are also to be provided to the system.

4.1.4 Hardware and Software requirements

As has been stated earlier, the motivation for the development of the system is taken from the warehousing problem of a large automobile company. It has been found out that the company has around 7000 items to be stored in the warehouse. There are 5 type of bins in the warehouse and few equipments to transport the items to and from the warehouse. It has also been observed that the transaction of data is not too voluminous to be stored on an inexpensive Personal Computer (PC) and thus it is felt that a PC-based solution would be more cost effective and beneficial. Therefore, the system has been developed on a IBM-compatible PC based on Intel's 80386 architecture. In order to make the system readily adaptable, it is felt that using the Microsoft Windows environment will be more effective. The reason is that Windows environment provides an in-built Graphical User Interface (GUI) which greatly enhances the user friendliness and the interaction between the system and the user. GUI provides graphical images, in the form of what are commonly known as icons, which are self explanatory about their possible functions. Therefore, using GUI completely eliminates the need on the part of the user, to know how to operate the system and thus reduces the burden of being trained particularly for using the system. Keeping in view the above advantages of GUI, provided by Windows, the Warehouse Information System is developed in Microsoft Visual Basic language which operates in the Windows environment. This language is chosen because it provides the necessary amalgamation of processing power of a traditional language, like C, and an in-built data base manager which helps in fast and efficient processing of data, stored in the database. Since the system is developed in Windows environment, the user should have Microsoft Windows loaded on one of the hard disks on his PC. Windows requires a minimum amount of Random Access Memory (RAM) of about 2 Megabytes (Mb) and preferably 4 Mb for improved performance.

In essence, to be able to use the Warehouse Information System, the user should have the following at his / her side :

- a PC 386 or higher version with one or more hard disks and at least one external diskette drive.
- Disk Operating System (DOS) Version 3.1 or higher.
- Microsoft Windows Version 3.1 or higher loaded on one of the hard disks of PC.

4.2 System Design

4.2.1 Database Design

The "Warehouse on-line Information System" requires a variety of data which includes data about various products to be stored in the warehouse, data regarding various equipment to be used in the warehouse for the purpose of transporting the products between ports and storage locations, data regarding all the bins used in the warehouse for the purpose of storing the products and data for all the ports which are used for receipt and delivery of the products. In addition, data for all the storage locations available in the warehouse is also required. The details of data needs for the system are given in Section 4.1.3 above but this data is to be put into a proper format so that access to the required data is fast and efficient. In order to do that, different relationships among the data have to be worked out and data has to be normalized and grouped together. The normalized relations among various data components are listed below (key fields are in *italics*) :

Product : *product code*, product name, stock level.

Bin : *bin id*, *bin type*, space reqd, maximum permissible height of storage.

Product - Bin relationship : *product code*, *bin type*, capacity of bin.

Equipment : *equipment id*, cost, capacity, manpower reqd, maximum accessible height, operating cost, horizontal velocity, vertical velocity.

Equipment - Bin relationship : *equipment id*, *bin type*, loading time, unloading time.

Rack : *rack id*, type, no of rows, no of columns, x and y coordinates.

Rack occupied : *rack id*, *row no*, *column no*, bin id, product code, product quantity.

Rack free : *rack id*, *row no*, *column no*, no of free spaces.

Request master : *request no*, type, incoming date and time, due date, execution port.

Request received : *request no*, *product code*, product quantity, bin id, equipment id.

Port : *port id*, type (input, output or both), x and y coordinates.

As mentioned earlier also, all this data is kept in the form of tables in a database. The structure of one of these tables is given in Table 4.1 with all the field names, types and maximum length of each field :

Field Name	Field Type	Field Size
Equipment ID	String	8
Equipment Type	String	1
Operating Cost	Real	System Dependent
Horizontal Velocity	Real	System Dependent
Vertical Velocity	Real	System Dependent
Manpower Reqd	Integer	System Dependent
Accessible Height	Real	System Dependent

Table 4.1 Equipment Table

4.2.2 Program flow chart

In this section, the entire computer program for the Warehouse Information System is illustrated with the help of flow charts. As mentioned in Chapter III there are several cases which are dealt with in the system both for stock assignment and order pick up. Therefore, for each case, a flow chart has been depicted describing the logical flow of control

pertaining to the case under consideration. These flow charts are depicted in Fig 4.3 to Fig 4.9 with sufficient details so as to enable the reader to comprehend easily what all is incorporated in the system and how different solution methodologies, described in Chapter III, are implemented in designing the system. Moreover, these charts can also be used as a reference tool to help the user in understand the system in a much better way. Fig 4.3 depicts a simple flow chart which gives an overview of the whole system followed by more illustrative flow charts for the following different cases :

4.2.2.1 Stock assignment problem

First, we will deal with the problem of stock assignment to warehouse. As mentioned in Section 3.3 of previous chapter, there can be two cases in this problem depending upon the type of items to be stored in the warehouse.

4.2.2.1.1 Single item type is to be stored

Here, only single type of item is to be stored in the warehouse. Solution method for this case is described in Section 3.3.1 Again this can be subdivided into two more cases depending upon the equipment selection procedure.

4.2.2.1.1.1 Equipment preselected by the user

Here, equipment is selected by the user before submitting the request to the warehouse. The solution methodology for this case in given in Section 3.3.1.1. Program flow chart for this case is given in Fig 4.4.

4.2.2.1.1.2 Equipment is to be selected by the system

Here, system has to select the equipment for the user along with the locations for storage. Solution method for this specific case is dealt with in Section 3.3.1.2 and the flow chart for it is given in Fig 4.5.

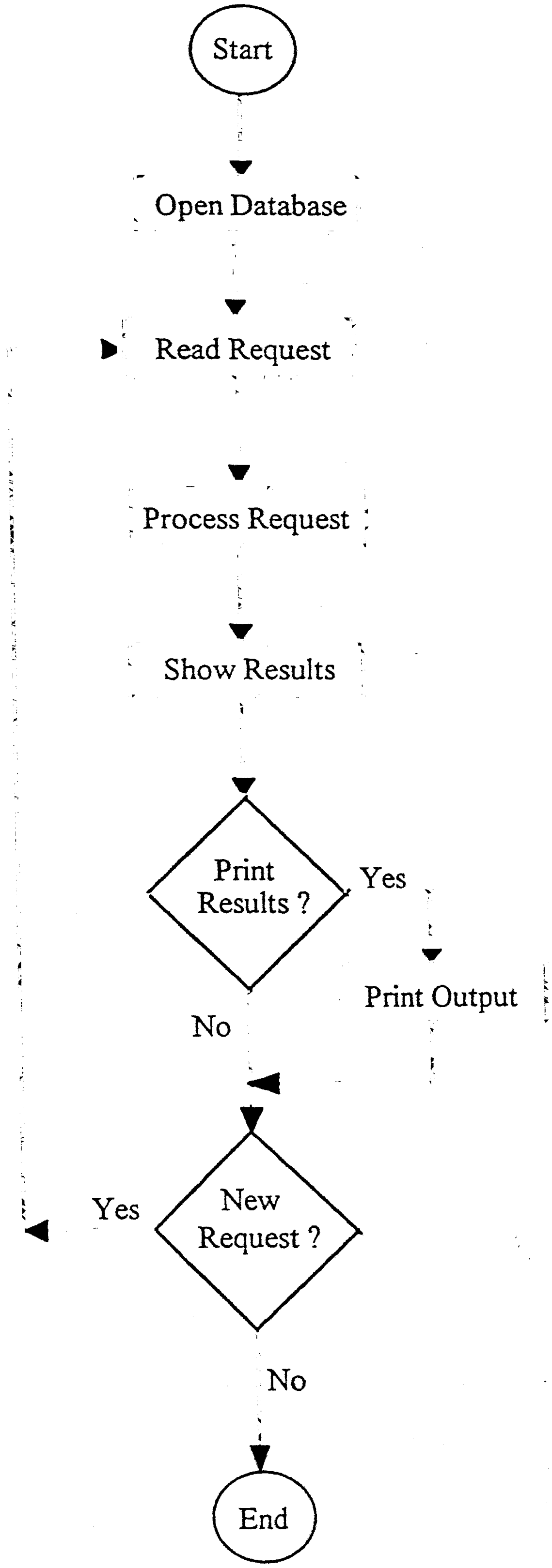


Fig 4.3 Generalized Process Flow Chart

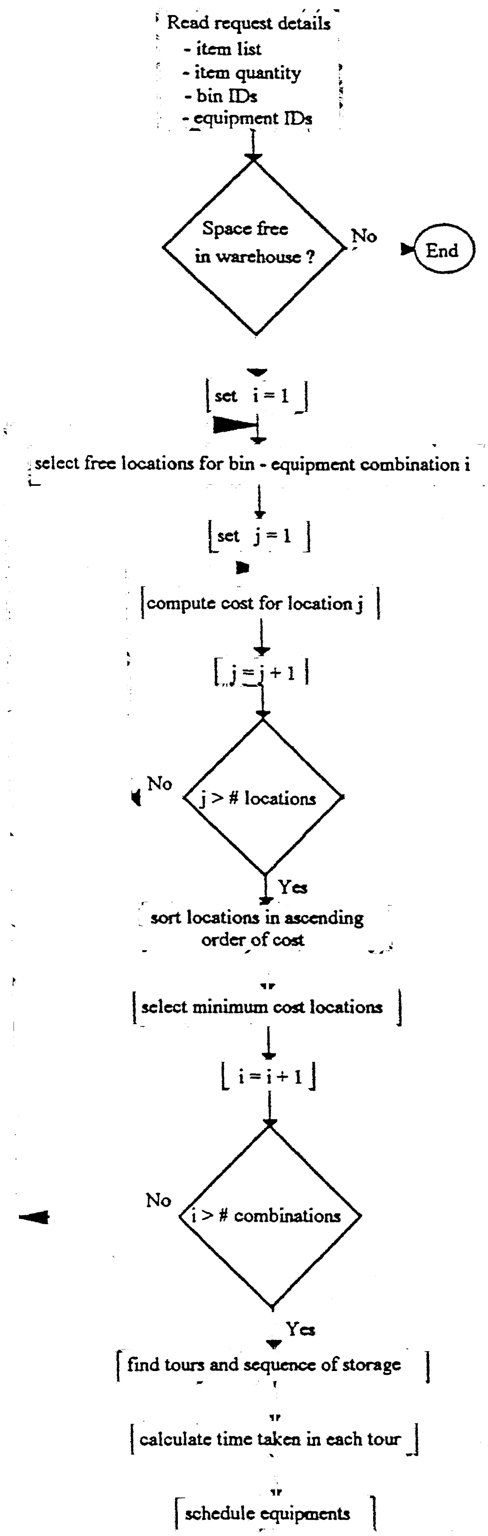


Fig 4.4 Storage Request (Case 4.2.2.1.1.1)

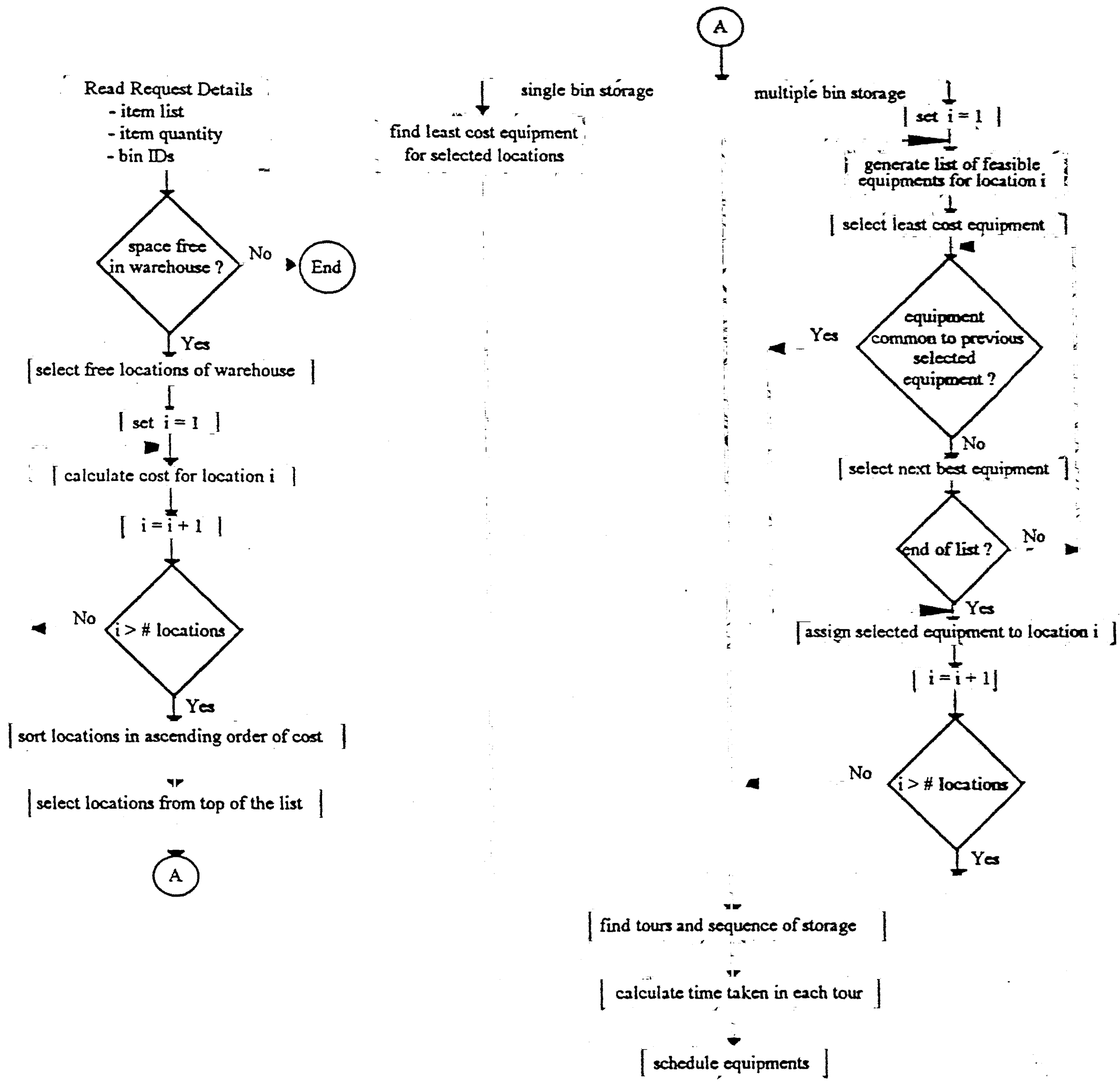


Fig 4.5 Storage Request (Case 4.2.2.1.1.2)

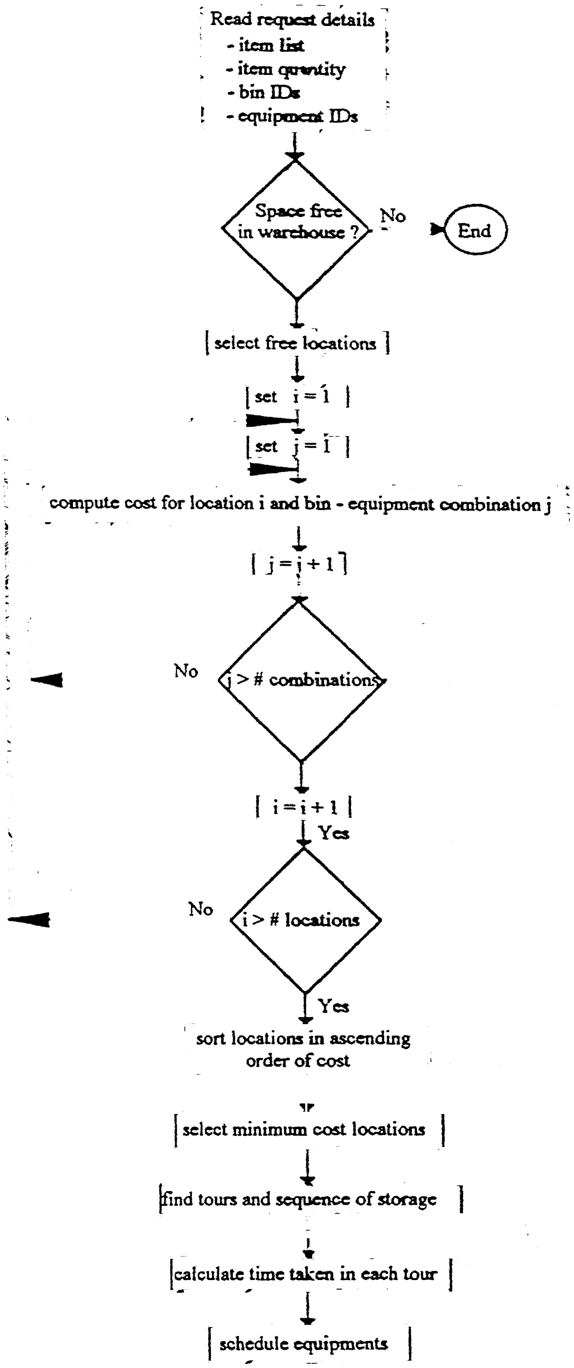


Fig 4.6 Storage Request (Case 4.2.2.1.2.1)

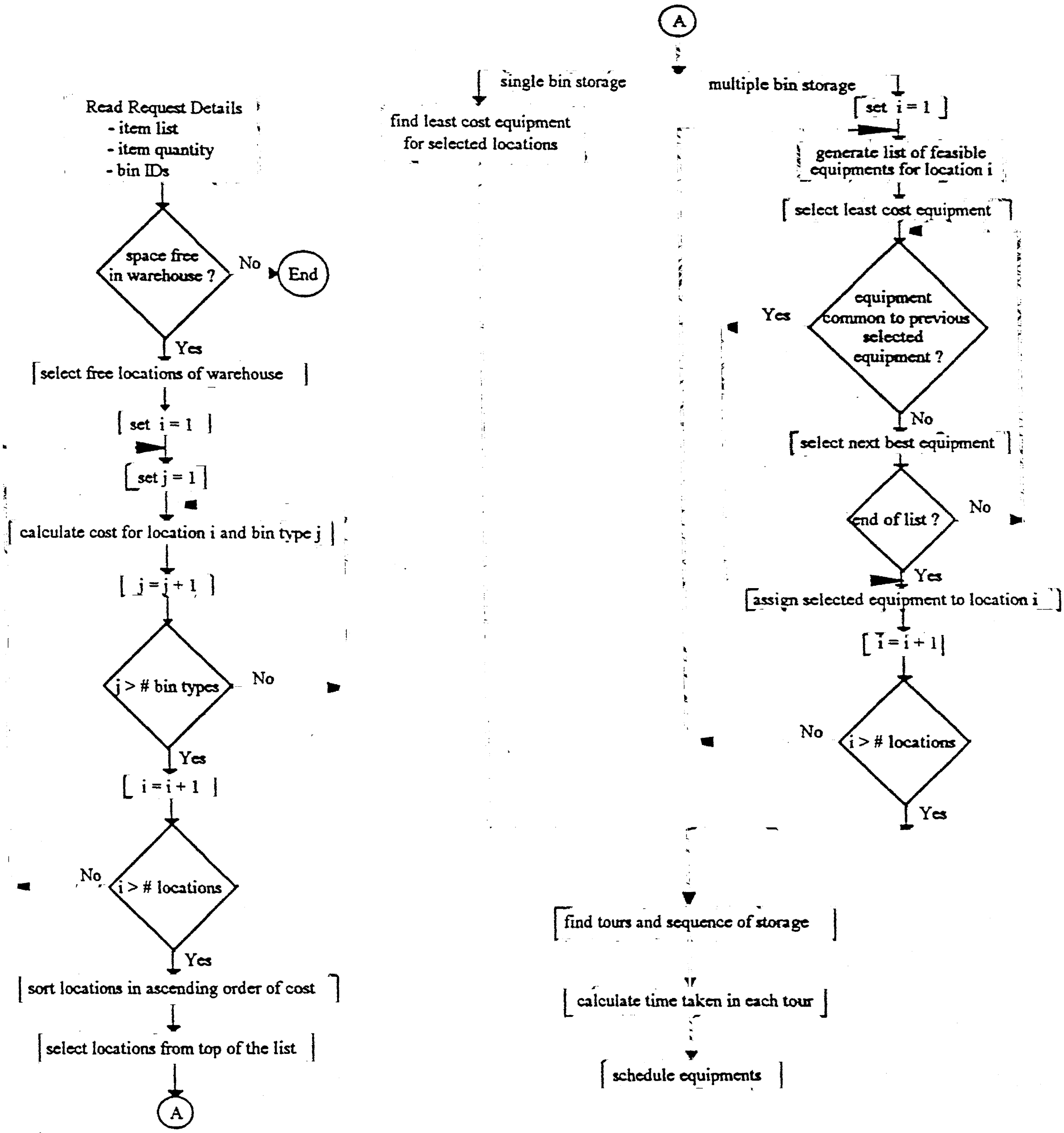


Fig 4.7 Storage Request (Case 4.2.2.1.2.2)

4.2.2.1.2 Multiple item types are to be stored

In this case the number of types of items to be stored in the warehouse is more than one. The solution method for this case has been discussed in Section 3.3.2 of previous chapter. This case also can be sub divided in two categories depending upon the mode of equipment selection

4.2.2.1.2.1 Equipment is preselected by the user

Here, equipment used for the purpose of storing the items in the warehouse are selected by the user before submitting the request to warehouse. This specific case can be solved by the method described in Section 3.3.2.1. The program flow chart for this case is shown in Fig 4.6.

4.2.2.1.2.2 Equipment is to be selected by the system

Here, the system has to select the equipment used in execution of the request along with the locations which are to be accessed. The solution methodology for this specific case is given in Section 3.3.2.2 and flow chart is shown in Fig 4.7.

4.2.2.2 Order pickup problem

The problem of order pick up has been discussed in Chapter II and the solution methodology is described in Section 3.4. As described there, this problem can be categorized in two different categories depending upon the mode of equipment selection - when equipment is specified by the user and when equipment is selected by the system itself :

4.2.2.2.1 Equipment preselected by the user

In this case, equipment is already selected by the user itself and the system need not to select the equipment at its own. The solution method for this specific case is given in Section 3.4.1. This method is illustrated through a flow chart in Fig 4.8.

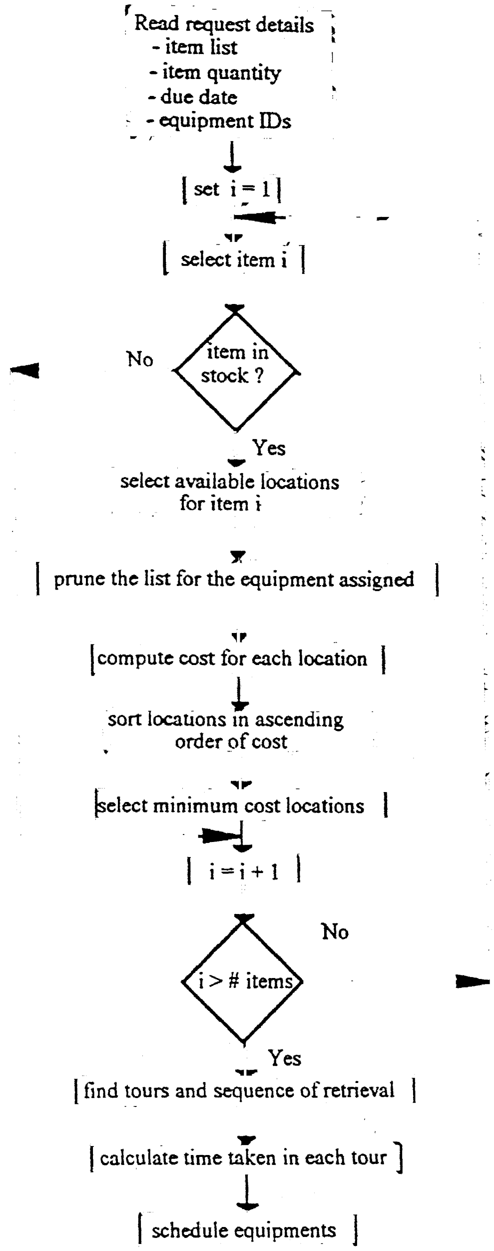


Fig 4.8 Retrieval Request (Case 4.2.2.2.1)

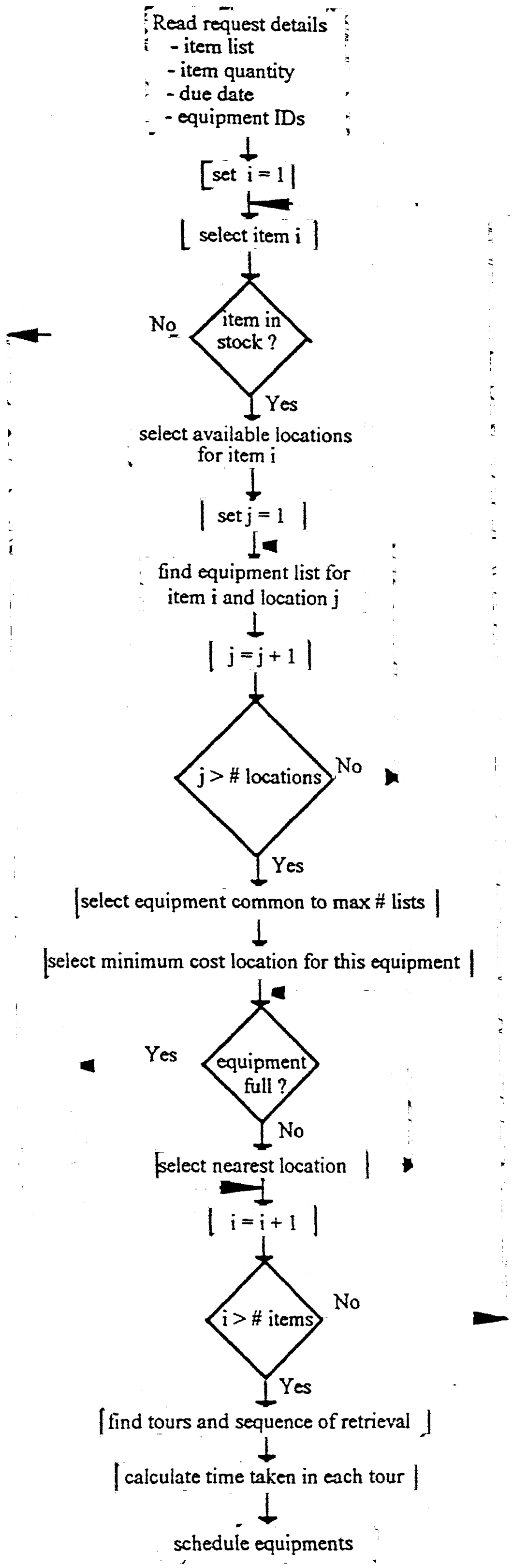


Fig 4.9 Retrieval Request (Case 4.2.2.2.2)

4.2.2.2.2 Equipment is to be selected by the system

Here the equipment selection is done by the system along with the selection of locations from where the items are to be picked. Solution method for this case is discussed in detail in Section 3.4.2 and flow chart for it is depicted in Fig 4.9.

4.2.3 Data encoding for input

The system takes the input either in the form of some query or in the form of a request. In the first case when the user asks for a specific query, input of data is in the form of the unique identification number assigned to that particular warehouse resource. While submitting a request for the processing purposes, the user has to specify the product codes of the items listed in the request and quantities of the listed items. The identification number of the bins are also to be given in case the request is for storing the items in the warehouse. Apart from this, while initializing the database for a warehouse, the system requires all the relevant information about all the warehouse resources. All the above information is entered in terms of data which is taken from the user in some encoded form, typically, in the form of numbers and text strings. Following is a description of data formats required for each type of data used in the system :

Text String : identification number of all resources and request number, type of equipment, rack, bin and port, type of request.

Numeric (real) : velocities of equipment, operating cost, accessible height, permissible storage height, location of ports and racks, loading unloading times, capacity of bin.

Numeric (integer) : manpower reqd., number of rows and columns in a rack, capacity of equipment.

4.2.4 Output Design

The format of the output generated by the Warehouse Information System, essentially, depends upon the input given by the user to the system. If the input given to the system is

in the form of a query, then the system displays the result of the query on the screen, along with all the relevant information, sought by the user, with proper labeling to enhance the legibility of the output. The other case may be that the input to the system is in the form of a request. In this case, the system displays all the information regarding the processing of that request on the screen for visual inspection. This information, typically, consists of the data regarding the request such as the identification number of the request, its submission data and time, its type (whether storage or retrieval), items listed in the request, their quantities, identification number of the bins involved in the request, equipments needed to transport items and the address and sequence number of the storage locations which are to be accessed for executing the request. The system also provides the facility to take hard copy of the output of the request to facilitate physical execution of the request. Also, a facility to monitor certain parameters of the warehouse and to take report of the performance of the warehouse on the basis of those parameters is provided. The parameters evaluated by the system are

- utilization of the equipments used for transporting the products. It gives the information about the idle time of all the equipments existing in the warehouse in a certain period of time. Therefore from this it can be found how much a particular equipment is being utilized for the purpose of request processing.
- utilization of the storage locations i.e. racks. It gives the information regarding the space utilization of each rack of warehouse in a certain period of time. From this it can be found how much a rack is utilized for storing the items in the warehouse.
- frequency of retrieval of products stored in the warehouse. It provides the information about the turnover frequency of all the products stored in or retrieved from the warehouse. This information helps in deciding upon the optimal policy of storing different items in the warehouse for example high turnover items may be stored near to the output port so as to facilitate their retrieval fast and efficient.

In essence this report provides some sort of snapshot of the warehouse at the time when it is asked for.

Average time taken in stock assignment / order pickup : this report gives the information regarding the average time taken in the execution of a request (both storage and retrieval) including the delay, if any, either because of unavailability of the equipment or because of unavailability of the product in warehouse. It helps the warehouse manager in the assessment of storage and retrieval policy adopted for the warehouse. It also helps in finding out bottleneck in the operation of warehouse and to some extent its reasons.

CHAPTER V

USERS GUIDE

This chapter provides the user, all the necessary instructions to use the Integrated Warehouse Planning System (IWPS). Here, it has been assumed that the user is well versed with the mouse techniques such as clicking and double clicking. In case, user is not very comfortable with the mouse techniques, he / she is referred to Microsoft Windows User's Guide. In the following text, apart from installing the system on a hard disk drive, various menu systems have been described in detail for better understanding of the functioning of the system.

5.1 Installing IWPS

To install and use the Integrated Warehouse Planning System (IWPS), following equipment and hardware is needed :

- any IBM PC or compatible with an 80386 microprocessor or higher.
- a minimum of 2 Mb RAM, for better performance 4 Mb or more is desired.
- an external or internal hard disk drive.
- MS-DOS version 3.1 or higher and Microsoft Windows version 3.1 or higher already installed on the hard disk drive of the PC. DOS version 5 is recommended.

In order to install IWPS on the hard disk drive, insert the distribution disk in the external diskette drive and start Windows. Go to the program manager's File menu and select Run... command from there. A dialog box will appear on the screen to enter the command

you want to run. Enter *a: setup* and press the Return key. Here *a:* is the name of the drive in which the distribution disk is inserted. If the drive is something other than *a:* then give the appropriate name in place of *a:*.

5.2 Menu System

WIS provides a wide range of options for the user to select from. The main menu provides 7 choices namely **Warehouse**, **Process**, **Evaluate**, **Query**, **Print**, **Options** and **Help** and is displayed as shown in Fig 5.1. These choices are described in detail in the text to follow:

5.2.1 The Warehouse menu

The **Warehouse** pull down menu offers many choices to the user for a variety of use. It provides options to **open** and **close** the warehouse database, a whole set of pull down menus for **maintenance** work and **start data** option to enter existing warehouse data into the system for the first time. And last but not the least, **exit** option to shut down the system.

Open

This is used to open a database to store all the information regarding all the resources like products, bins, equipments, racks and ports of the warehouse. The database stores the data regarding the functioning of the warehouse as well. When this option is chosen, a file dialog box appears on the screen and asks for the name of the database to be opened. If the user enters a database name which does not exist then it asks the user whether to create a new database or not. In case of confirmation of the creation of a new database, it creates a new database for the user with no data, whatsoever, in it.

Close

It simply closes the currently open database. When selected, it asks the user to confirm the closing of the database. On confirmation, the system does the necessary house keeping and closes the database.

Fig 5.1 Main Menu

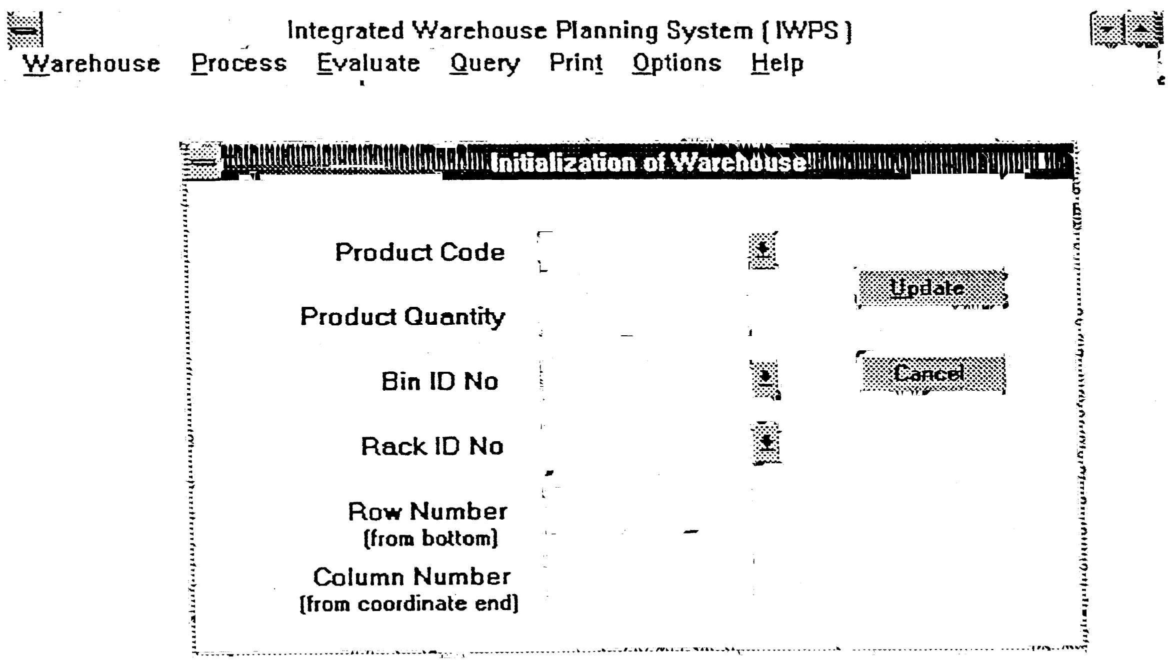


Fig 5.2 Warehouse Initialization

Maintenance

This menu option helps the warehouse manager in keeping the warehouse database up-to-date. All the relevant data of a warehouse can be broadly classified into two categories - resource data and functional data. Resource data is the data regarding resources of the warehouse like products, stored in the warehouse, bins in which products are stored, equipments which are used for transportation, storage locations or racks where bins are kept and the ports at which products are received or shipped. Functional data refers to data regarding the requests received in the warehouse and the performance measurement data. This menu item provides options to **add** or **delete** various warehouse resources. In addition to these two, one more important sub-option **clean-up** has been provided, keeping in view the limited disk space of the PC. This sub-option cleans up all the functioning data of the warehouse from the database but not the resource data. The user is advised to use this sub-option time to time so that disk space is always available to the system. Note that if this sub-option is selected it removes all the functional data which is irrecoverable. Therefore user should ensure that before using this, all the necessary data has been hard-copied in the form of reports.

While providing data for the resources of warehouse, user will be required to enter the coordinate positions of some of the resources e.g. racks and ports. In this regard, the user is supposed to give the coordinates according to Cartesian X-Y-Z axes system. In the information system, an assumption is made regarding the orientation of the coordinate system according to which X axis is parallel to the aisles, running between the racks and Z axis is parallel to the vertical direction. Therefore the user is advised to enter the coordinate positions keeping in view the assumed coordinate system orientation described above.

While entering the data about product, bin and equipment, the user is asked to describe various relationships among them, in the form of data. These relationships are also stored

into the system as part of the resource data. Here, note that when any of the three resources is deleted from the system with the help of **delete** sub option then all the relationship attached to that particular resource will also be get deleted from the system. Therefore every time the user enters a new resource into the system, the relevant relationships are also to be entered afresh.

Start data

The **start data** option is one of the most useful options, which is provided so that the user can enter all the information of an existing warehouse into the system at the time of starting. This option requires that the data about various resources of the warehouse exist in the system beforehand. Therefore, if it is required to start the system afresh, first all the data regarding products, bin types, individual bins, equipments, storage locations and ports is to be entered into the system with the help of **maintenance** option described above. Next the existing status of the warehouse can be given to the system with the help of this option. User should note here that this option can be used only once. If it is tried to use more than once on the same database, the system reports data integrity error (see Section 5.3). The data entry form for this option is shown in Fig 5.2.

5.2.2 The Process menu

The **Process** pull down menu enables the user to submit requests to the system. It has two options - **Storage** and **Retrieval** corresponding to the two types of requests which are possible in the warehouse. Whenever any of these options is selected a data entry window appears on the screen, as shown in Fig 5.3, where the user can enter the required data for the request. The user has to enter all the data about the request in this data entry window, such as number of the request and items of the request and their quantities. In addition to this, for a retrieval request, user has to enter the due date whereas for a storage request, user has to enter the bin identification numbers which contain the items to be stored. In the

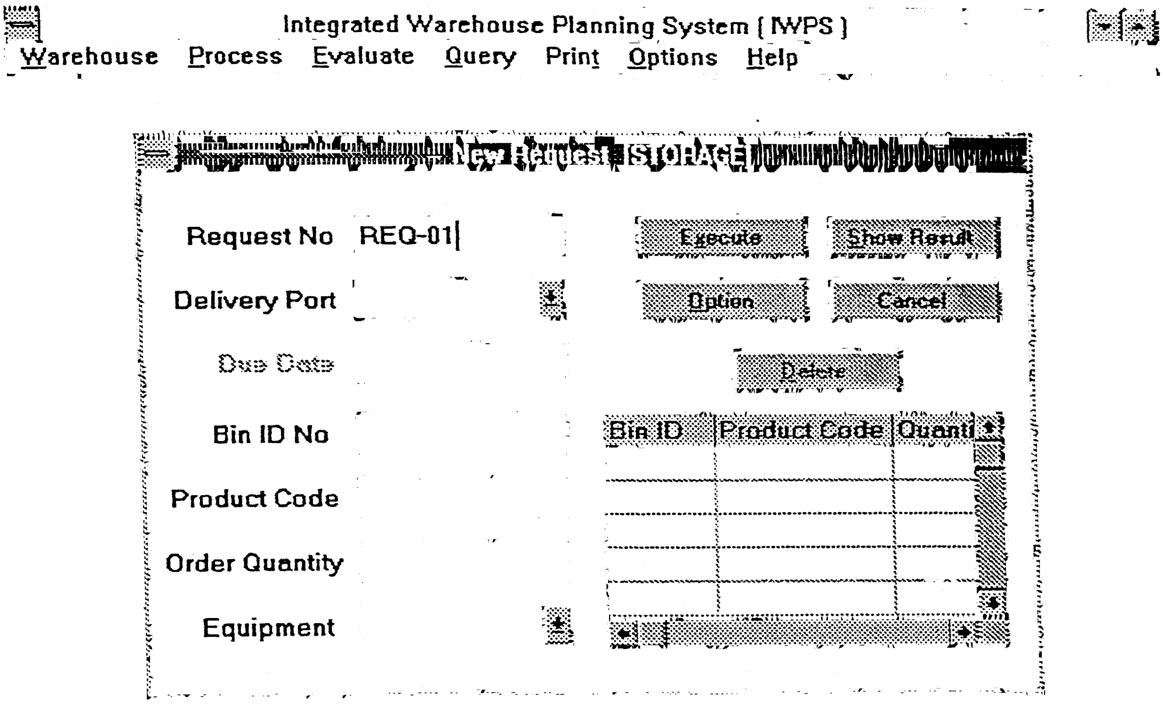
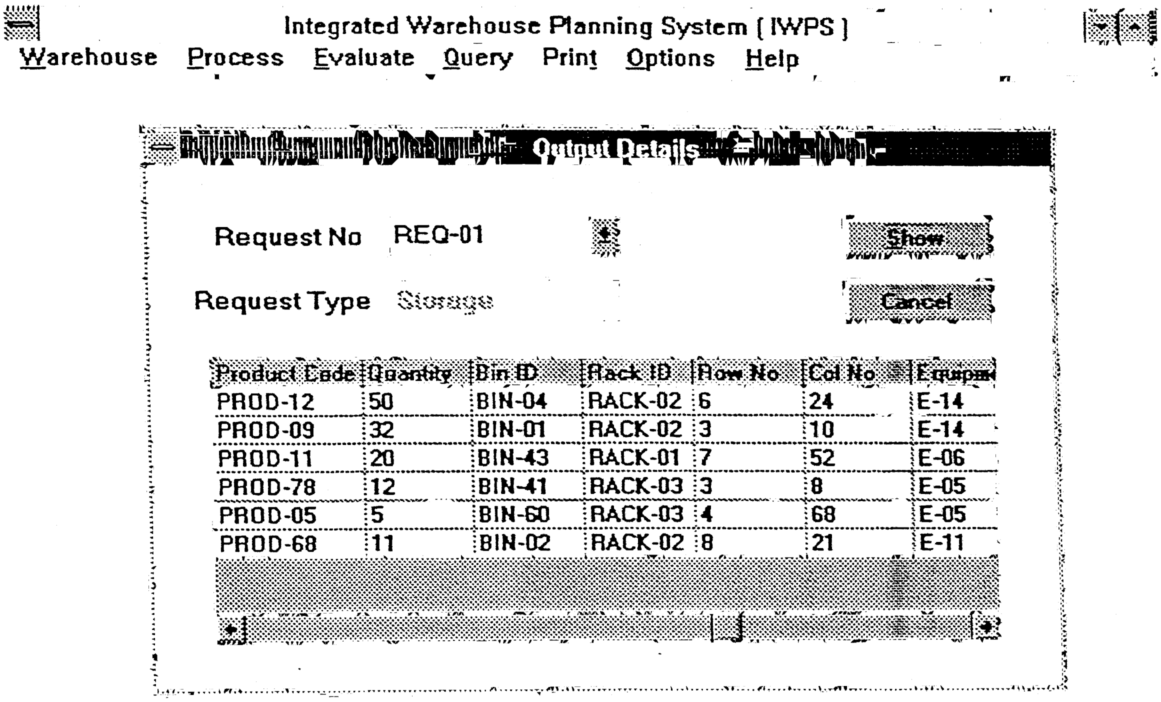


Fig 5.3 New Request

data entry window a button, labeled as "Option", is provided so as to facilitate the setting of processing options (discussed later in Section 5.2.6) at the time of entering the request itself. After entering the data for a request and pressing the add button on the window, request is processed by the system and the output of the entered request is displayed on the screen in a window with all the relevant details. A sample output is shown in Fig 5.4. In the data entry window, the user is provided with an "Execute" button. If the user presses this button then the request is executed and the system data is updated accordingly. In case this button is not selected then the request is automatically discarded and the system is restored to its previous state.



Product Code	Quantity	Bin ID	Rack ID	Row No	Col No	Equipm
PROD-12	50	BIN-04	RACK-02	6	24	E-14
PROD-09	32	BIN-01	RACK-02	3	10	E-14
PROD-11	20	BIN-43	RACK-01	7	52	E-06
PROD-78	12	BIN-41	RACK-03	3	8	E-05
PROD-05	5	BIN-60	RACK-03	4	68	E-05
PROD-68	11	BIN-02	RACK-02	8	21	E-11

Fig 5.4 Request Output

5.2.3 The Evaluate menu

This menu item provides options to evaluate certain pre-defined warehouse performance measures such as **rack utilization, equipment utilization** and **product frequency**. When any of these options is selected the corresponding parameter is evaluated. One important thing to note here is, that all the three performance measures are taken for a time period. Therefore, evaluation of any of the parameter is done from the time it is evaluated last till the time of selecting the option. Also, these parameters are not evaluated by the system itself until and unless these options are selected by the user. By transferring the power of

evaluation of parameters to the user, the flexibility of the system has been increased because, now the user can decide on the time interval of evaluating the parameters. This enhances the adaptability of the system to different working environment. Though, by doing this, the probability of missing some important data, because of the negligence on the part of the user, is increased.

5.2.4 The Query menu

This menu item provides the user an interface by means of which information regarding all the resources of the warehouse can be sought at any point in time. It provides options to make query for all the resources of warehouse such as **product, bin, equipment, rack** and **port** as well as options for **request** and **output**. In all the options, the unique identification number of the resource, for which the information is required, has to be entered by the user. In case of last two options, the corresponding request number is to be given to the system.

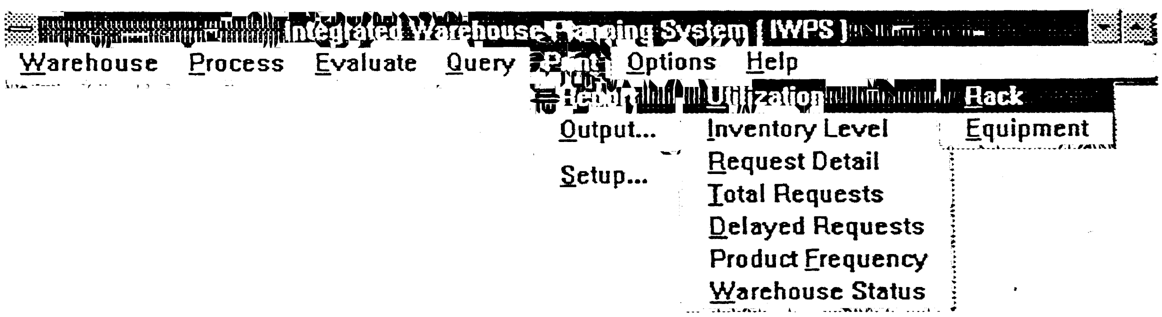


Fig 5.5 Print Menu

5.2.5 The Print menu

This pull down menu offers various options for printing the required documents useful for record keeping purposes as well as for management information purpose. All the options provided under this menu item are shown in Fig 5.5. The options include option to print **reports** for decision making purposes, to print the **output** of a request and to **setup** the printer for user specific needs such as to change the fonts or style. The **report** option includes various sub-options for different type of reports such as utilization report of racks and equipments, report of current stock in the warehouse, all the details of a particular request, a summary report of all the requests received in the warehouse, a summary report of all the requests which have been delayed, report for frequency of different products and a report showing the current status of the warehouse. User is advised to use this option for taking reports, before using the **cleanup** sub-option of the **maintenance** option in **warehouse** menu item, so as to take a hard copy of all the required data before all the data get deleted. A sample report is shown in Fig. 5.6.

5.2.6 The Options menu

It enables the user to set various options, which govern either the **environment** of the warehouse or the **processing** methodology of executing a request.

Environment

If this option is chosen by the user, a dialog box appears on the screen, as shown in Fig 5.6, where various options can be set as per the user's choice. In this box, user can set the value of **smallest transporting unit** to be either bin or product. Similarly, the criterion for computing the **similarity coefficient** can also be set from this box. In addition to these, criterion for **distance function** computation and the nature of the distance function can be governed from here, by setting the involved parameters to particular values. Also, the **unit**

length measurement can be changed from here, by giving different values to the respective options.

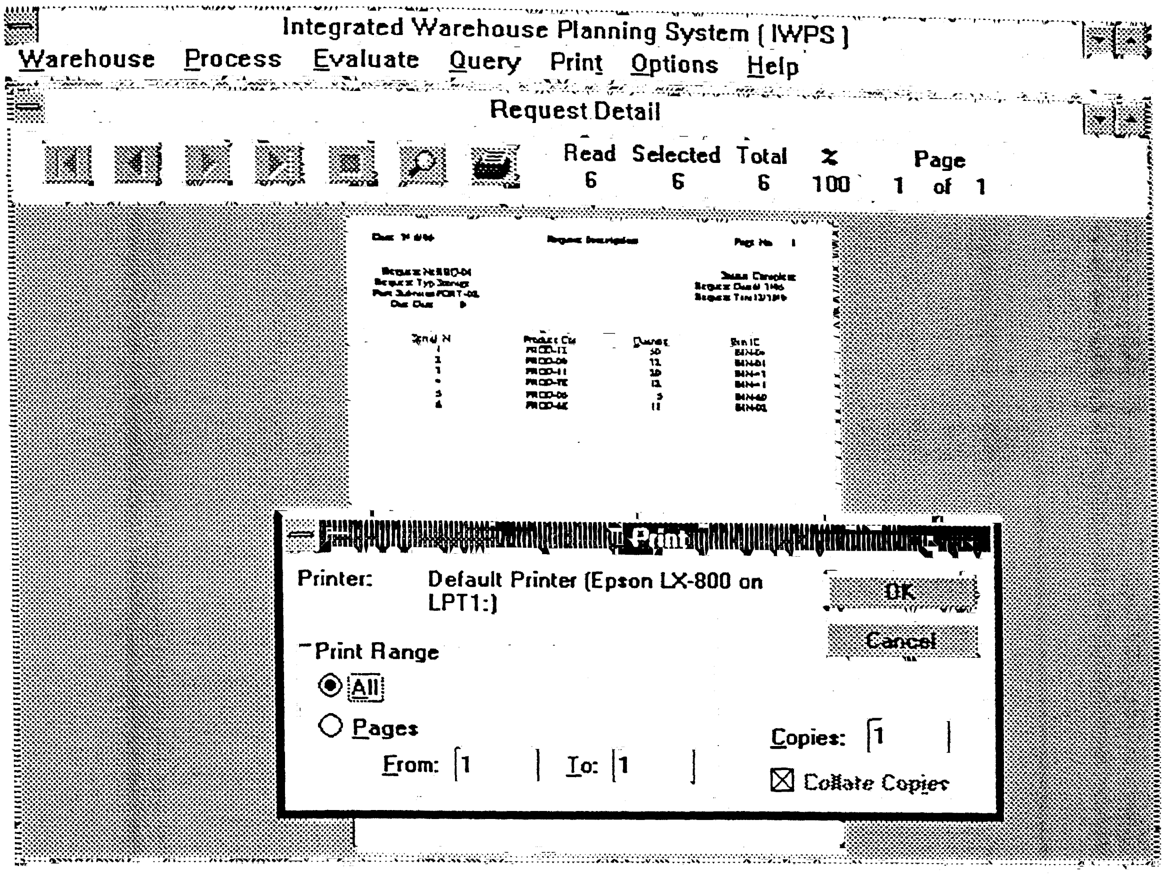


Fig 5.6 Sample Report

Processing

Through this option, user is able to specify the way in which a particular request will be dealt by the system. Here also, a dialog box appears on the screen, as depicted in Fig 5.8, where the user can set the **storage method** and **retrieval method** to be adopted by the

system while processing a request. In addition to these, here the user can also specify the mode of **equipment selection**. One more option is there which reads out **region of dissimilarity cost**. This option is a bit more technical in the sense that it asks the user to specify the region around a storage location which is taken care of while computing the dissimilarity cost for that location. User is referred to Chapter II for more information regarding the computation of dissimilarity cost.

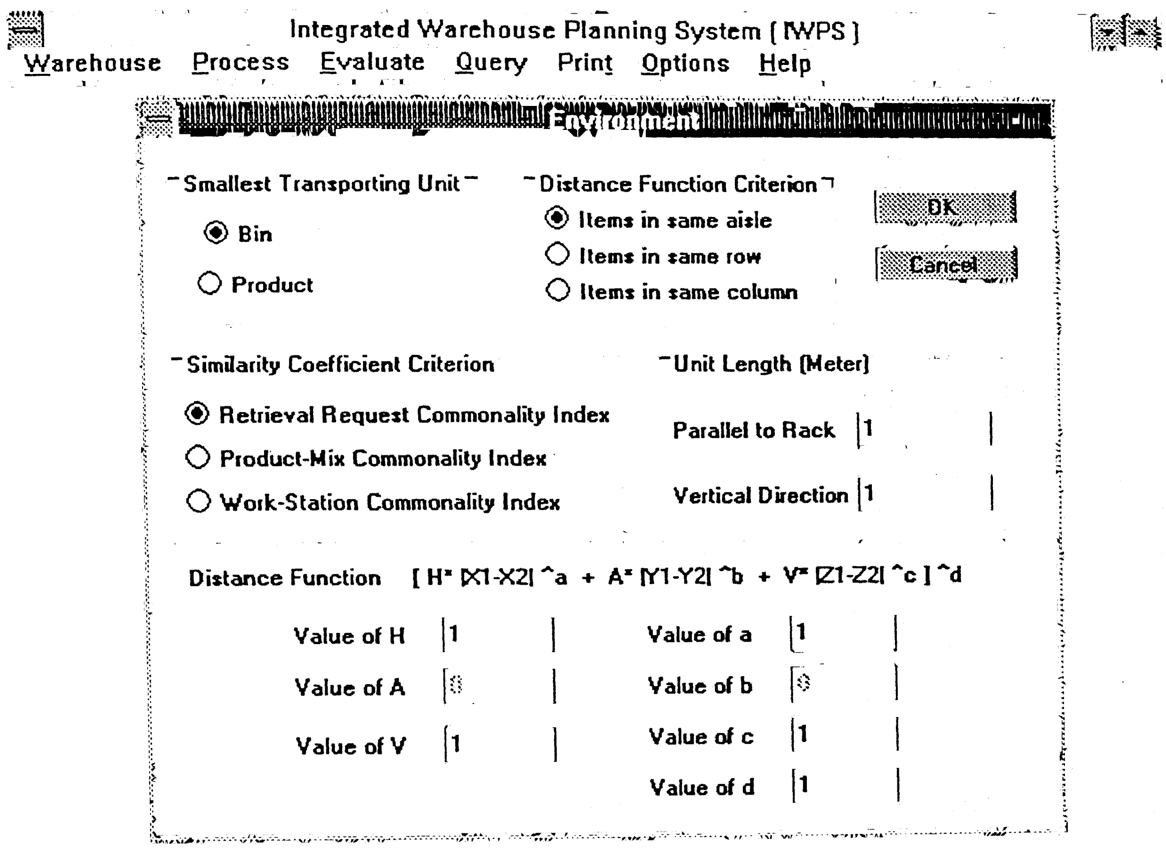


Fig 5.7 Environment Option

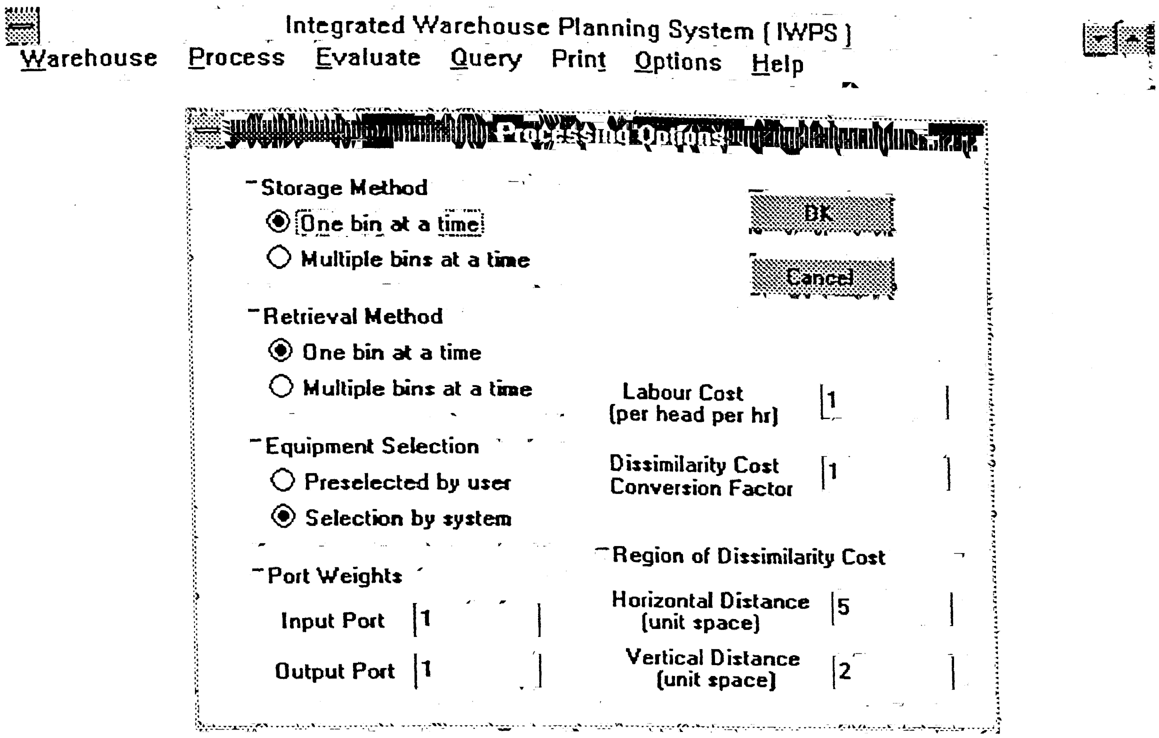


Fig 5.8 Processing Option

5.3 Error Messages

The Warehouse Information System generates various error messages to indicate undesirable conditions which are generated by erroneous user input. Though the messages given by the system to the user are self - explanatory, the various error messages and their possible reasons are given below :

1) Bin add error

This error is reported when an attempt is made to add a new bin into the system without any bin type being added. The proper sequence is to add a bin type first and then add a bin into the system.

2) Database not found

It is generated while using the **open** option of the **warehouse** menu for opening a database. It occurs when the specified database is not found on the disk. In strict sense this is not an error message as it is always reported whenever a new database is being created. It simply signifies that the specified database is not present and the system is going to create it afresh.

3) Data too large

It occurs when the user attempts to add some resource or submit a request to the system with the help of maintenance / add options with an identification number which is too large for the system to handle. The user is informed about the upper limit on the size of the identification number with the error message so that rectification can be done accordingly.

4) Duplicate error

This error is generated by the system when the user makes as attempt to add some warehouse resource into the system, using the **maintenance / add** options, with an identification number which is already existing.

5) Frequency error

This error is reported when product frequency is attempted to evaluate, through **evaluate** menu item, without being any request submitted to the system. The user should first submit few request into the system and execute them and then the frequency should be evaluated.

6) Incompatible Database

This error is reported by the information system when the user specifies a database, not created by the system, in the **open** option of **warehouse** menu. If the specified database is

created by the system then it indicates that some damage to that database has been done through some other means. It signifies that the specified database cannot be used by the system.

7) Insufficient data

This error is reported by the system, when the **start data** option is used to enter the existing data of a warehouse into the system, without entering the data about all the resources. The user should, first enter all the resource data into the system, with the help of the **maintenance** menu and then use the start data option.

8) Integrity error

It is reported when the user tries to enter some data into the system through **start data** option when data is already existing in the system. This error signifies that an attempt is made to destroy the integrity of the system. The user is advised not to attempt entering data into the system through this option when the data already exists.

9) Invalid file extension

This error is reported when user attempts to open or create a database with a file extension other than "mdb". The default setting of this extension in the system is "mdb" and user is advised not to give any other extension. Same error is reported if the user enters a file extension other than "dbf" while using the option **Product mix commonality index** in the **Options / Environment** dialog box. Here the user is asked to enter the name of a dBase file which is having the product mix data.

10) *item* not found

This error is generated while querying the system for any of the resources or the request. It usually occurs when the user presses the "Search" or "Delete" button in the dialog box without specifying the identification number of the *item* being queried.

11) Type mismatch

This error is reported at the time of entering data into the system. It indicates that the data type which is entered by the user is not of the type which is expected. It occurs, typically, when some numeric data is expected and user attempts to enter data in character form.

12) Utilization error

It occurs when the user attempts to evaluate either equipment utilization or rack utilization through **evaluate** menu item. It signifies the absence of the related resource data into the system. The user should first enter the resource data into the system and then use this menu item to evaluate the desired parameter.

CHAPTER VI

CONCLUSIONS AND FUTURE SCOPE FOR WORK

6.1 Conclusions

In this dissertation an attempt has been made to develop a warehouse planning system which can help in efficient functioning of the warehouse. In the system, two major problems of warehouse, namely stock assignment and order pick up, have been dealt with. Different possible cases of these two problems have been taken into consideration in the developed system so that the system works more closely to a real life warehouse. These cases vary from very simple ones like single bin storage and single bin retrieval to very general ones like multiple bin storage with more than one type of item, each having multiple bins to be stored. In the system several parameters have been used to simulate the actual working conditions of a warehouse. The system is equipped with all the necessary user interface so that the user can have total control on the system. This interface vary from simple messages to much more complicated data entry windows which guides the user in interacting with the system. The system also provides all the necessary documents in printed form which will surely make the system more adaptable to an organizational environment. The system has been developed in Windows environment, which, definitely, will be a great advantage for the user in handling and using the system for his / her purpose because Windows provides an excellent graphical user interface which renders the training for using a new system, unnecessary.

6.2 Future scope for work

As mentioned above, two major problems have been addressed in this dissertation. In almost all the different cases of these two problems, some simple heuristics have been used to arrive at the results. The solutions given by these heuristics, obviously, will not be the exact optimal solution of the problem. Therefore, there is an ample scope for improvement at this front so that the solutions yielded by the system can become more near to the exact solutions. The system has been developed in a modular way so that the modified solution methodologies for different cases can be plugged into the system without much of problem. Apart from this, order pick up problem has been dealt with in the system in a very primitive way. This particular problem should be addressed in more detail so as to make the system complete from warehouse operation point of view. Moreover, this system does not incorporate the clustering of orders at the time of retrieval which may be one of the additions to the system.

One of the limitations of the present system is that at the time of retrieval, at a time one stock keeping unit is moved which in the present system is assumed to be a bin. Therefore, by making a provision for the movement of an item itself, this assumption can be relaxed to make the system more realistic. Another limitation of the system is that it does not take into account the distribution of the requirements of various items on different work stations at the assembly line, which, in some cases, may give a better picture of the demand pattern of products than that given by the retrieval pattern at the warehouse. It could not be incorporated into the developed system because of the unavailability of required data. Though, the option for its consideration is provided in the system so that in future it can be incorporated into the system as an extension of present system.

In addition to the above possibilities, there is an scope to integrate the system vertically with an automated retrieval system which will retrieve the items of the request from the locations decided by the developed system and in a sequence determined by this system.

This system can also be integrated horizontally with an automated receipt and despatch system so as to fully automate the entire warehouse operations.

One more possible extension of the present work may be to integrate an inventory control module to the present system as the system already keeps track of the stock level of all the products in the warehouse.

APPENDIX A

The following text provides necessary mathematical explanation of various computations which are to be done in order to solve the stock assignment problem of the warehouse discussed in Chapter II and Chapter III.

A.1 Distance Function

The distance function between two locations i and j i.e., d_{ij} is defined as the weighted horizontal, vertical, and across the aisle distance between them .

$$d_{ij} = [\,H\,\{\,d\,|X_i - X_j|\,\hat{}\,a + e * \min[\,(X_i + X_j), (2 * L - X_i - X_j)\,]\} + A\,|Y_i - Y_j|\,\hat{}\,b + V\,\{\,(\,f\,(Z_i + Z_j) + g\,|Z_i - Z_j|\,)\,\hat{}\,c\,\}\,]\,\hat{}\,d \quad \text{............ A.1}$$

Where

H is the weight for the horizontal distance .

V is the weight for the vertical distance.

A is the weight for across the aisle distance.

L is the length of rack along the aisle.

Xi, Xj are the x-coordinates of locations i and j, along the aisle.

Yi, Yj are the y-coordinates of locations i and j, across the aisle.

Zi, Zj are the z-coordinates of locations i and j (vertical movement).

a, b, c, d are the constants to determine the type of distance function, that is, rectilinear, Euclidean or squared Euclidean.

f and g are the dependent binary variables which take value 0 or 1 such that their sum does not exceed 1.

Some of the possible cases of parameter settings are

(a) within the aisle movement

- equipment has to be brought down to the ground level before horizontal movement

  $d = 1,\ e = 0,\ a = 1,\ f = 1,\ g = 0,\ c = 1$

- equipment can move horizontally without changing the vertical height position

  $d = 1,\ e = 0,\ a = 1,\ f = 0,\ g = 1,\ c = 1\ (\ y_i = y_j\ )$

- shortest distance movement between the location

  $d = 1,\ a = 2,\ e = 0,\ g = 1,\ c = 2,\ d = 1/2$

(b) across the aisle movement ($y_i <> y_j$)

  $d = 0,\ a = 1,\ c = 1,\ b = 1,\ f = 1,\ g = 0,\ d = 1$

(c) Eucledian (shortest distance) movement

  $d = 0,\ a = 2,\ e = 0,\ b = 2,\ f = 0,\ g = 1,\ c = 2,\ d = 1/2$

So, if only rectilinear horizontal distance is to be include, while calculating the distance between two locations, keep the value of H, a and d equal to one and weights V, A, b and c will take value zero. Likewise, these weights take the values according to the requirement of the distance function.

A.2 Dissimilarity Cost

There are three possible cases in which the dissimilarity cost is computed. These cases are discussed below along with the methodology of computing the dissimilarity cost :

A.2.1 Single bin of an item is to be stored

In this case only one bin is to be stored at one location out of available "m" locations. So this case is similar to single facility location in which one facility is to be located at one location out of some pre-specified number of available locations. Here, a dissimilarity cost

will be associated with each available location say location i. Let the dissimilarity cost be denoted by a_i.

$$a_i = \sum_{O \in S} f_o * d_{i(I_{i,o})} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad A.2$$

where

a_i = dissimilarity cost of location i

f_o = joint retrieval frequency of item o and item to be stored.

d_{ij} = distance between locations i and j.

$I_{i,o}$ = Location of item o closest to the location i.

S = Set of all items in the warehouse.

A.2.2 More than one bin of same item are to be stored

In this case, more than one bin of same item is to be locates so the interaction cost of locating the same item, at more than one location, will also be considered. Let the total dissimilarity cost of locating the item at both the locations i and j be denoted by a_{ij}.

$$a_{ij} = a_i + a_j - p_{ij} \quad \ldots\ldots\ldots\ldots \quad A.3$$

where p_{ij} is the interaction term and is computed by the equation :

$$p_{ij} = \sum_{O \in S} f_o * b_{ij} * \text{Maximum}[\, d_{i,(I_{i,o})},\ d_{j,(I_{j,o})} \,] \quad \ldots\ldots\ldots \quad A.4$$

where $b_{ij} = 1$ if $I_{i,o} = I_{j,o}$

$= 0$ otherwise.

This interaction term is computed taking into consideration that in case, for any item "o", same location is close to both the selected locations for the item being stored in it, it has to be associated with only one of them, which will be the location closest to it.

A.2.3 More than one bin of different items are to be stored.

This case is similar to the case of multi-facility location, in which new facilities to be located have some interaction among them. So there will be a dissimilarity cost associated with each location for a particular type of item and there will be an interaction factor for two type of items being located at two locations.

Let

a_{ik} = dissimilarity cost of locating item i at location k.

a_{jl} = dissimilarity cost of locating item i at location l.

a_{ijkl} = dissimilarity cost of locating item i at location k and item j at location l.

Then

$$a_{ijkl} = a_{ik} + a_{jl} - p_{ijkl} \quad \text{...........} \quad \text{A.5}$$

where p_{ijkl} is the interaction factor mentioned above. The expressions for the various costs mentioned above are given below. The notations used here are same to that of used in Equation A.2.

$$a_{ik} = \sum_{O \in S} f_{io} * d_{k(I_{k}o)} \quad \text{........................} \quad \text{A.6}$$

$$a_{jl} = \sum_{O \in S} f_{jo} * d_{l(I_{l}o)} \quad \text{........................} \quad \text{A.7}$$

$$p_{ijkl} = \sum_{O \in S} b_{kl} * \text{Maximum}[\, f_{io} * d_{k(I_{k}o)},\ f_{jo} * d_{l(I_{l}o)} \,] \quad \text{.......} \quad \text{A.8}$$

The summation O, that is, over all the stored items, used in computing various dissimilarity costs, as mentioned above, can be user specified also. The need for this arises from the fact that due to equipment limitations some locations may not be served by the same equipment. The other reason may be that due to space limitations, some locations may not be served in the same tour. Another possibility is that there may be some items which cannot be retrieved together. So on the basis of these limitations a user can easily judge what items and locations are to be included in the computation of the dissimilarity cost.

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